VITAL SIGNS MONITORING PLAN

Phase II Report

National Park Service
Greater Yellowstone Network

GRYN
Greater Yellowstone Inventory & Monitoring Network
Bighorn Canyon NRA, Grand Teton NP, Yellowstone NP

September 30, 2003

EXECUTIVE SUMMARY

The Greater Yellowstone Inventory and Monitoring Network (GRYN) is one of 32 National Park Service (NPS) Inventory and Monitoring (I&M) Networks created to monitor the long-term ecosystem health of the nation's parks. The parks of the GRYN include Yellowstone National Park, Grand Teton National Park, John D. Rockefeller, Jr. Memorial Parkway, and Bighorn Canyon National Recreation Area. The GRYN Vital Signs Monitoring Plan Phase II Report summarizes the activities undertaken to select vital signs used for monitoring the state of the parks' natural resources. Three phases make up the Vital Signs Monitoring Plan: Phase I consisted of the compilation of background data on the Network parks and conceptual modeling; Phase II describes those activities completed in Phase I and the selection and prioritization of vital signs; and Phase III will include the entire scope of information in Phases I and II, as well as monitoring objectives, sampling designs and protocols, and data management and analysis procedures.

Bighorn Canyon National Recreation Area was created to provide recreational opportunities on Bighorn Lake and the surrounding lands, as well as to preserve the scenic, scientific and historic resources contained within the area, including those resources within the Pryor Mountain Wild Horse Range and the Yellowtail Wildlife Habitat Area. Grand Teton National Park and adjacent John D. Rockefeller, Jr. Memorial Parkway were set aside for the conservation of their vast scenic and geologic values and indigenous flora and fauna, including the high-alpine scenery of the Teton Range. Finally, Yellowstone National Park makes the GRYN unique in that it is the world's first national park and home to a vast array of geothermal features, charismatic fauna and numerous vegetation zones.

The primary goal of the National I&M Program is to assess the long-term ecological health of the park units. Other benefits of the program include the ability to detect change in resource condition and evaluate resource response to management actions. Moreover, the program aims to create baseline knowledge of the condition of park resources for park scientists and those in academia or the private sector, and to create an effective method for data management, analysis, and reporting. Through information and data sharing, the program hopes to increase public awareness of park activities and resources. To assess the ecological health of the parks, the I&M program first focuses on inventories of park resources. While this task has largely been completed for the GRYN, some inventories are ongoing. Then, given basic inventory data, the program seeks to create a plan for monitoring in order to develop broadly based, scientifically sound information on the current status and long-term trends in the health, composition, structure, and function of park ecosystems.

The I&M program was created through the Natural Resource Challenge, a method of improving natural resource stewardship in the parks. The Natural Resource Challenge requires managers to know the condition of natural resources under their stewardship and monitor long-term trends in those resources to conserve them unimpaired for future generations. Furthermore, monitoring is legally mandated through the NPS Organic Act, as well as numerous other acts and executive orders. Moreover, vital signs monitoring achieves the Category 1 goals found in the Government Performance and Results Act (GPRA), which requires that federal agencies account for money spent by reporting on the results of their activities.

To grasp the wealth of information currently available about park resources, the GRYN compiled background information on the resources at risk, and past and current monitoring efforts. Resources at risk include threatened and endangered species (gray wolves, bald eagles, Canada lynx and grizzly bears), aquatic resources (including threats to the Outstanding Natural Resource Waters within Yellowstone and Grand Teton National Parks and 303(d) listed streams in all GRYN park units), and other threats, such as habitat loss, invasive species, human use, and threats to air

quality. Furthermore, almost 200 monitoring-related projects have occurred within the parks of the GRYN. These projects include information on the following resources: atmospheric resources, amphibians and reptiles, birds, mammals, flora, fire effects, recreation effects, aquatic resources, water quality, and geologic resources.

To identify proposed candidate vital signs for selection and prioritization, the GRYN, under the guidance of the National I&M Program, undertook the process of creating conceptual ecological models. Conceptual models, by definition, formalize our understanding of natural processes. This formalization facilitates cross-discipline, cross-community dialogue between scientists, resource managers, and the general public. In addition, conceptual models provide an understanding of the structure, function, and interconnectedness of park ecosystems, enabling the identification of vital signs for assessing ecosystem health. After analysis of many possible types of conceptual models, the GRYN decided to concentrate efforts on creating box-and-arrow schematic diagrams of 14 ecosystem divisions. These divisions included nine terrestrial models (separated using the National Vegetation Classification Standards, along with lumping of some similar ecosystems), two aquatic models, and one geothermal model. The models identified the drivers, stressors, response variables, outcomes, and metrics of the ecosystem modeled, as well as the interconnectedness between these elements. Furthermore, the models highlighted the position of the proposed candidate vital signs within these ecosystem components. The conceptual modeling process identified many large-scale ecosystem-shaping processes, known as drivers. Drivers, as defined by the I&M program, are major, naturally occurring forces of change that have large-scale influences on the attributes of natural systems. Drivers can be natural or human-induced and operate on the national or regional levels. Drivers identified through the conceptual modeling process include: climate, human impacts, fire, exotic species, insects and disease, herbivory, Clark's nutcrackers, morphometry, parent material and soil type, hydrogeomorphology, elevation and topography, the magma chamber, and geothermal activity. The conceptual modeling process was particularly helpful in identifying proposed candidate vital signs that were not identified through other scoping processes.

Other scoping work was done by the GRYN in an effort to identify possible vital signs for monitoring. These processes including the Delphi survey process and a workshop series. The Delphi survey was an internet-based questionnaire sent to subject-area experts and park personnel that consisted of nominating possible vital signs for monitoring, and then subsequently ranking them on a scale of importance. In addition, the GRYN held park-specific workshops to gain insight from park managers on the value of the conceptual modeling and Delphi processes, as well as the process used to select important vital signs. This selection process consisted of 13 yes/no questions pertaining to the ecological relevance, response variability, managerial relevance, feasibility of implementation, and interpretation and utility of the proposed candidate vital signs. After peer review by park staff and contributing scientists, the GRYN hosted a Vital Signs Monitoring Workshop, during which invited subject-area experts and park managers ranked the proposed candidate vital signs using the selection criteria. After scoring the results, the GRYN had a ranked list of 121 candidate vital signs to bring to the Technical Committee Vital Signs Selection Meeting.

The Technical Committee, comprised of park personnel, serves as the main advisory body to the GRYN Program Manager. The park-specific expertise of these individuals was critical to the vital signs selection process, as many of the invited subject-area experts were unable to give critique on the managerial relevance of the proposed candidate vital signs. Furthermore, the Technical Committee provides guidance to the Board of Directors, whose approval of the selected vital signs is mandatory. To choose the vital signs to be monitored by the GRYN, the Technical Committee began with the 40 top-ranked vital signs from the Vital Signs Monitoring Workshop. Then, Technical Committee members added any lower-ranked vital signs to their list, based on ecological or managerial importance. After eliminating redundancies, the members screened the entire list again, based on importance to understanding ecosystem health or park management actions. Those vital signs that strongly passed or failed the screen were respectively retained on, or deleted from, the list. For the vital signs that garnered neither strong support nor resistance, the members added the vital sign to the list if the vital sign is currently being monitored—even minimally—since teaming with existing programs would allow the Network to leverage its funds and expand its monitoring program. This process resulted in a list of 44 proposed final vital signs to be prioritized. Themes addressed by the selected vital signs—climate, disease and exotics, human impacts, geothermal, species and communities of concern, air quality, and water quality—range broadly in temporal, spatial, and functional scales, plus include issues of high ecological and managerial relevance across the three Network parks.

The Technical Committee rated 11 of those 44 vital signs as top priorities for Network funding because they provide one of the following: (a) basic, critical information needed to make decisions; (b) information that helps describe and understand the broader system; or (c) information needed by management (e.g., threatened and endangered species). These top-priority vital signs will be considered first during Phase III of the program. In addition, the members provided three additional categories (i.e., beyond [1] top priority) under which a vital sign could fall, vital signs for which: (2) at least a minimally acceptable monitoring program is in place; (3) some work is being done, but only part of the vital sign is being monitored, temporal or spatial scale is inadequate, or more work is necessary; or (4) very little work is being done and the vital sign may need to be inventoried before a monitoring program can be developed.

After prioritization was accomplished, the proposed vital signs list was taken to the Board of Directors for approval, along with a description of the selection process and a short explanation of the vital signs. The Board members approved the vital signs list with the understanding that small changes to names of the vital signs could occur in the future, that major changes to the list would require Board approval, and that the full list may be outside the possible funding obtained by the GRYN. Changes to the list, particularly after the development of monitoring protocols has begun, are expected by the National I&M Program.

Following the Board of Directors meeting, the GRYN hosted its annual Science Committee meeting for peer review on the vital signs selection process, the vital signs selected, the strategic framework to be used during Phase III for development of monitoring programs, and the draft version of this report. Science Committee members provided insightful comments on the organization and presentation of the list of vital signs, as well as the prioritization process and outcome. Theses comments will help guide the Network in Phase III. Moreover, committee members suggested a change in prioritization of some vital signs, the addition of two vital signs they felt were important to accurately monitor ecological health, and the renaming or splitting of several vital signs. Additionally, Science Committee members provided a new way of categorizing the vital signs under broad groupings and two new conceptual models that integrate the broad groupings and show relevant ecological linkages between them. As a result of Science Committee guidance, the Network's final Phase II vital signs list contains 46 vital signs.

ACKNOWLEDGEMENTS

This monitoring plan was made possible through the National Park Service Natural Resource Challenge. Our gratitude extends to Abby Miller, Gary Williams, Steve Fancy, and Mike Britten for their direction and guidance on developing a Vital Signs Monitoring Program. We also appreciate the direction and insightful comments provided by the Greater Yellowstone Network Technical Committee: Tom Olliff, Steve Cain, Ann Rodman, and Kathy Tonnessen. We thank staff members Susan O'Ney and Chad Jacobson and former staff Laura Gianakos, Lane Cameron, and Pat Flaherty for their countless contributions. Glenn Plumb, who detailed as an ecologist for the Network during Phase II, made significant contribution to our understanding of the Greater Yellowstone ecosystem through the use of conceptual models.

Many individuals from within the Network parks also contributed to Phase I and Phase II of the Vital Signs Monitoring Plan; unfortunately we cannot mention them all. However we would like to especially thank Frank Walker, John Varley, Wayne Brewster, Todd Koel, Mary Hektner, Henry Heasler, Jennifer Whipple, Roy Renkin, Kerry Murphy, PJ White, Jeff Arnold, Rick Wallen, Doug Smith, Kerry Gunther, Terry McEneaney, Pat Bigelow, Dan Mahony, Christie Hendrix, and Brian Ertel from Yellowstone National Park; Darrell Cook, Rick Lasko, and Suzanne Morstad from Bighorn Canyon National Recreation Area; and Steve Haynes, Sue Wolff, and Dan Burgette from Grand Teton National Park. We also thank several unknown photographers for their works, which we obtained through the National Park Service public photo archives.

Many thanks to Anne Schrag from Big Sky Institute at Montana State University and Scott Bischke from Bozeman, Montana for their help preparing this report that is both comprehensive in content and enjoyable to read. Thank you both.

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SUGGESTED CITATION

Jean C, Bischke SD, Schrag AM. 2003. Greater Yellowstone Inventory and Monitoring Network Vital Signs Monitoring Plan: Phase II Report, September 30, 2003. National Park Service, Greater Yellowstone Network, Bozeman, MT. 99 pp. plus appendices.

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I. INTRODUCTION AND BACKGROUND

The Greater Yellowstone Network (GRYN) is one of 32 National Park Service (NPS) inventory and monitoring networks nationwide that, under the guidance of the Natural Resource Challenge, is creating a Vital Signs Monitoring Plan for assessing the health of park ecosystems. The GRYN is unique because it oversees monitoring in the world's first national park—Yellowstone. Grand Teton National Park (in Wyoming) and Bighorn Canyon National Recreation Area (in Montana and Wyoming) comprise the remaining parks of the GRYN.

This chapter provides background information on the Greater Yellowstone Network Inventory and Monitoring Program, including the following: natural resources of the GRYN, the importance of inventory and monitoring (I&M) programs, the objectives of the Network's monitoring plan, the critical threats and management issues currently facing GRYN parks, and monitoring work already underway.

A. AN INTRODUCTION TO THE GREATER YELLOWSTONE NETWORK

Ecosystems encompassed by the GRYN parks (Figure I.1) range from alpine tundra to lowland desert steppe. All three parks contain outstanding—and in many cases, rare—plant and wildlife species. Each park has important atmospheric, terrestrial, aquatic, and geologic resources. And each park faces a myriad of wide ranging threats, from insect pathogens to overgrazing by wild horses to atmospheric inputs from urban areas.

Grand Teton and Yellowstone National Parks make up the core of the 18 million acre (7.3

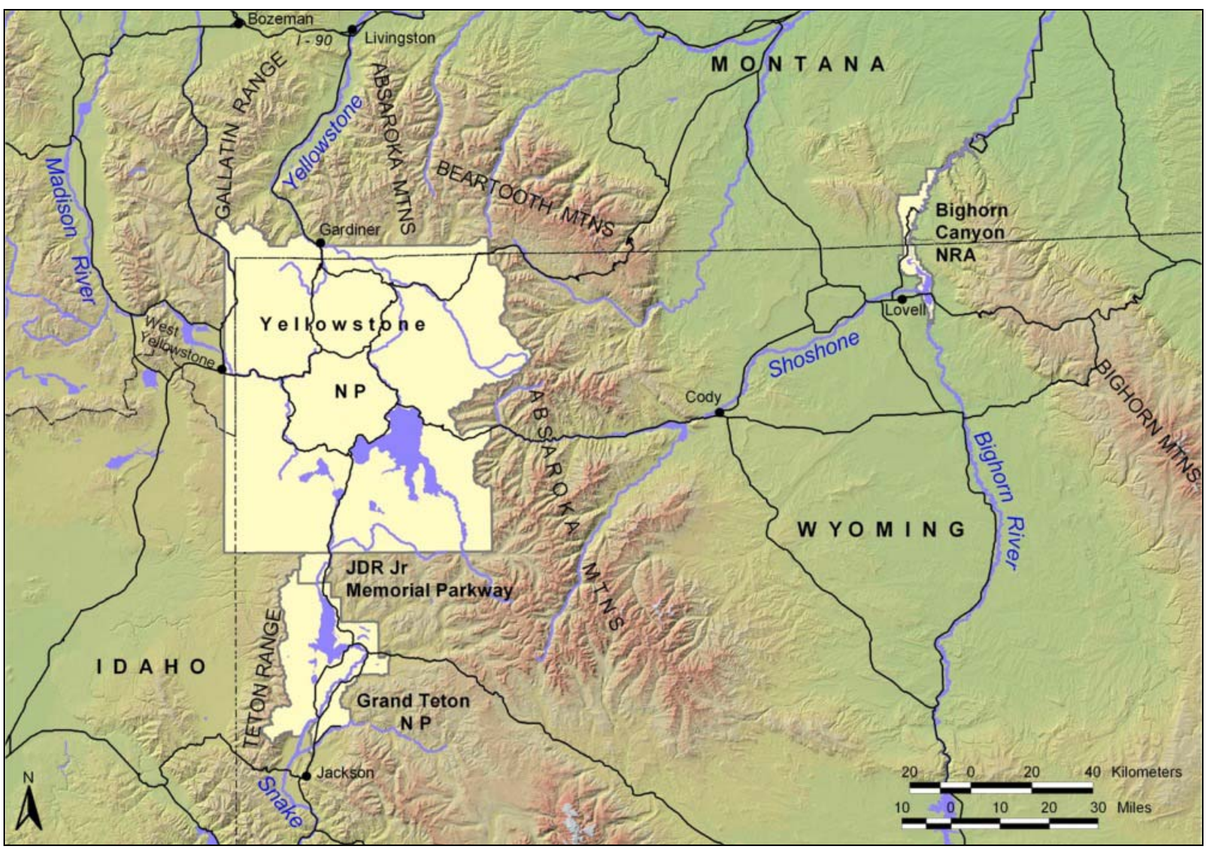

Figure I.1: The Greater Yellowstone Network parks, shown in light yellow.

million ha) Greater Yellowstone Ecosystem (Geographic Information & Analysis Center n/a), one of the largest, relatively intact natural areas in the contiguous United States. The two parks include a broad range of climatic zones, habitat types, and elevation profiles, and thus encompass great biological diversity. Sagebrush, lodgepole pine forest, and alpine meadows are but a few of the vegetative communities. The two parks contain Outstanding Natural Resource Waters (ONRW) that support a variety of aquatic and riparian species. Grand Teton and Yellowstone are home to one of only two stable populations of grizzly bears in the continental United States. Additionally, they host the largest herds of elk and free-ranging bison in North America, and serve as the only U.S. wintering ground for trumpeter swans.

Parks of the GRYN
Bighorn Canyon National Recreation Area (BICA)
Grand Teton National Park (GRTE) *which includes, for this report,* **John D. Rockefeller National Parkway (JODR)**
Yellowstone National Park (YELL)

Bighorn Canyon National Recreation Area (NRA) introduces juniper/mountain mahogany and ponderosa pine woodlands to the Network, plus unique desert cushion plant, shrubland, and riparian ecosystems. Unlike Yellowstone and Grand Teton, which are largely made up of forested, montane landscapes with open fescue grasslands and moist meadows, Bighorn Canyon is characterized by dry Wyoming Basin and Northern Great Plains landscapes. Still, BICA joins GRTE and YELL as part of the Greater Yellowstone Network for at least two reasons:

- geographical proximity results in lowered costs and people power needs for I&M activities, and
- overlap of some ecosystems means that similarities in species and habitat types, plus resource and management issues, will help streamline Network I&M study designs.

Ecosystem overlap is reflected in Omernick's (1987) level III classification of ecoregions of the conterminous United States. Yellowstone and Grand Teton lie within the Middle Rockies ecoregion. BICA lies mainly in Omernick's Wyoming Basin and the Northwestern Great Plains ecoregions, but contacts the Middle Rockies ecoregion on its east and west edges (a map is provided in the monitoring atlas of Appendix III).

All three parks have a temperate, semiarid climate, with precipitation being lowest in BICA. Throughout the Network, the general north-south orientation of the mountainous regions influences weather events. BICA, for example, lies in the rain shadow of the Beartooth Plateau (Nesser et al. 1997). Snow and rainstorms are most often pushed across the GRYN by prevailing west winds. Snow provides much of the Network's precipitation, though permanent snowfields and glaciers cover relatively small areas.

A combination of elevation, latitude, wind direction, and slope exposure controls the presence and abundance of vegetation. The uppermost alpine zone is characterized by alpine tundra. Engelmann spruce and subalpine fir forests usually dominate the subalpine zone. Below the subalpine zone, Douglas-fir is the dominant species in the climax community, and is most often associated with grand fir west of the Continental Divide and lodgepole pine and grasses east of the Divide. Below the montane belt is the foothill woodland zone with dry rocky slopes (characteristic of BICA) supporting mountain mahogany, ponderosa pine, and limber pine/juniper associations, depending on soil type, parent material, and aspect. The lower slopes of the mountains and the basal plain are dominated by sagebrush semidesert or steppe in YELL and GRTE, and short grass prairie in the northern portion of BICA.

Figure I.2 provides an informative cross section elevation profile of the Network parks, based on an arc from the Tetons to Yellowstone Lake to Bighorn Lake. While just a single slice across the parks, Figure I.2 nonetheless provides a revealing illustration of how elevation varies across Network: Grand Teton is largely dominated by alpine ecosystems, Yellowstone by mid-elevation mountainous country, and Bighorn Canyon by lowland desert environs.

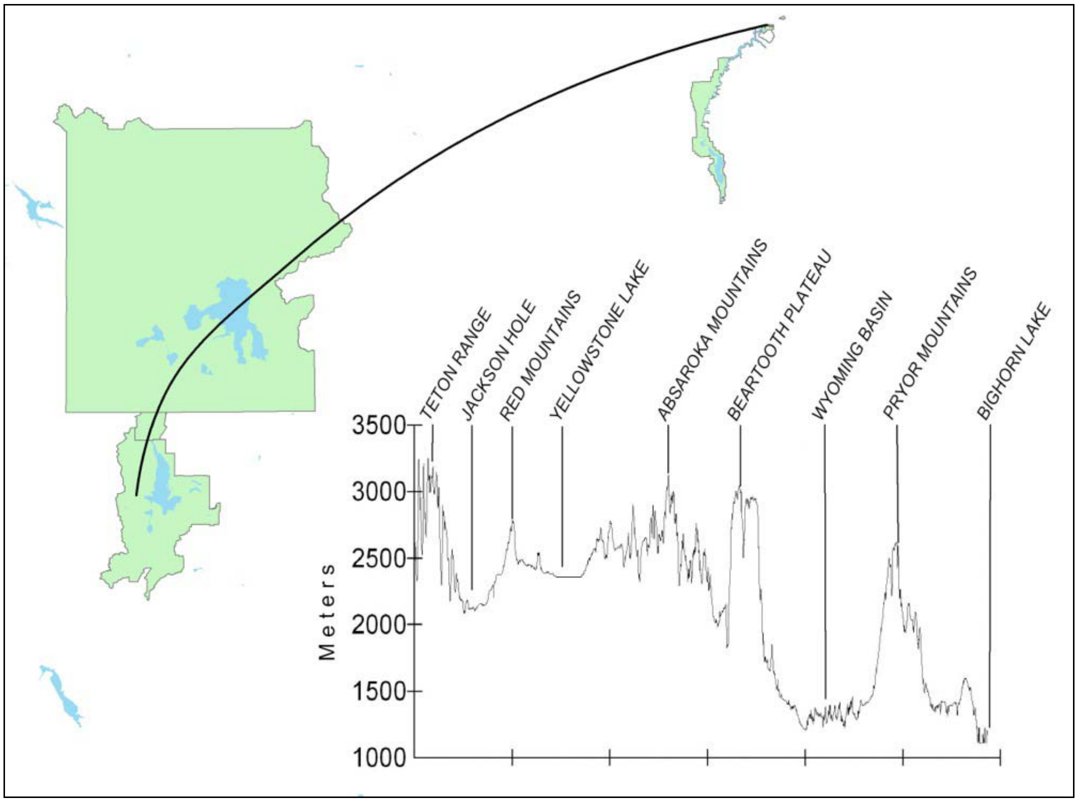

Figure I.2: Cross-section illustrating elevation profile across the GRYN. The inset map shows the path of the cross-section, from the high alpine country of GRTE, through YELL, to the lowlands of BICA.

Fauna in the Network parks is like that elsewhere in the Rockies; however, the mountains are generally isolated by stretches of arid lands and ranges often contain a group of species unique to the region. Common large mammals include elk, moose, deer, bighorn sheep, pronghorn antelope, mountain lion, bobcat, beaver, porcupine, and black bear. Grizzly bear and bison inhabit the western portion of the Network. Small mammals include mice, squirrels, pine martens, chipmunks, mountain cottontails, and bushytail woodrats. Common birds include the mountain bluebird, chestnut-backed chickadee, red-breasted nuthatch, ruby-crowned kinglet, pygmy nuthatch, gray jay, Steller's jay, and Clark's nutcracker. Rosy finches are found in the high snowfields, while blue and ruffed grouse are the most common upland game birds. Hawks and owls inhabit most of the region.

The sections that follow provide a more detailed look at the three parks of the Greater Yellowstone Network.

1. Bighorn Canyon National Recreation Area

Bighorn Canyon National Recreation Area (Figure I.3), located in southeastern Montana and north-central Wyoming, was created in 1966, following the construction of the Yellowtail Dam on the Bighorn River. The formation of BICA provided for the recreational use and enjoyment of Bighorn Lake and adjacent lands, and the preservation of the area’s scenic, scientific, and historic resources. Bighorn Lake winds through approximately 70 miles (112 km) of spectacular sheer canyons carved by the Bighorn River. Also considered a part of the park are 8,079 acres (3,269 ha) of the adjacent Pryor Mountain Wild Horse Range (managed chiefly by the Bureau of Land

Management [BLM]) and 19,424 acres (7,860 ha) of the Yellowtail Wildlife Habitat Area (managed cooperatively with the Wyoming Game and Fish Department [WGF]), providing habitat for waterfowl, upland game, and raptors.

Most of the roughly one-quarter million people a year who visit BICA remain within the Bighorn Lake corridor for recreation (see Table I.1 for GRYN visitor comparison); however, the recreation area also hosts uses non-typical to NPS, including hunting and livestock grazing.

Much of Bighorn Canyon's landscapes are characteristic of the Intermountain Semidesert Province (Bailey 1995). The topography consists of plains broken by isolated hills and low mountains. Sloping alluvial fans at the edges of the basins merge into flat plains in the center. Badlands are typical along the region's outer edges. Most of the topographic relief of the region is an expression of uplift of the Rocky Mountains that began about 70 million years ago. This uplift, having risen underneath layers of marine and sedimentary rock, created the numerous anticlines, synclines, domes, hogbacks, and other geologic landforms associated with erosion processes in the area. Soils—governed by the weathering of parent materials—are alkaline Aridisols and/or Entisols. Such soils often have lime and/or gypsum enriched subsoils that regularly develop into a caliche hardpan.

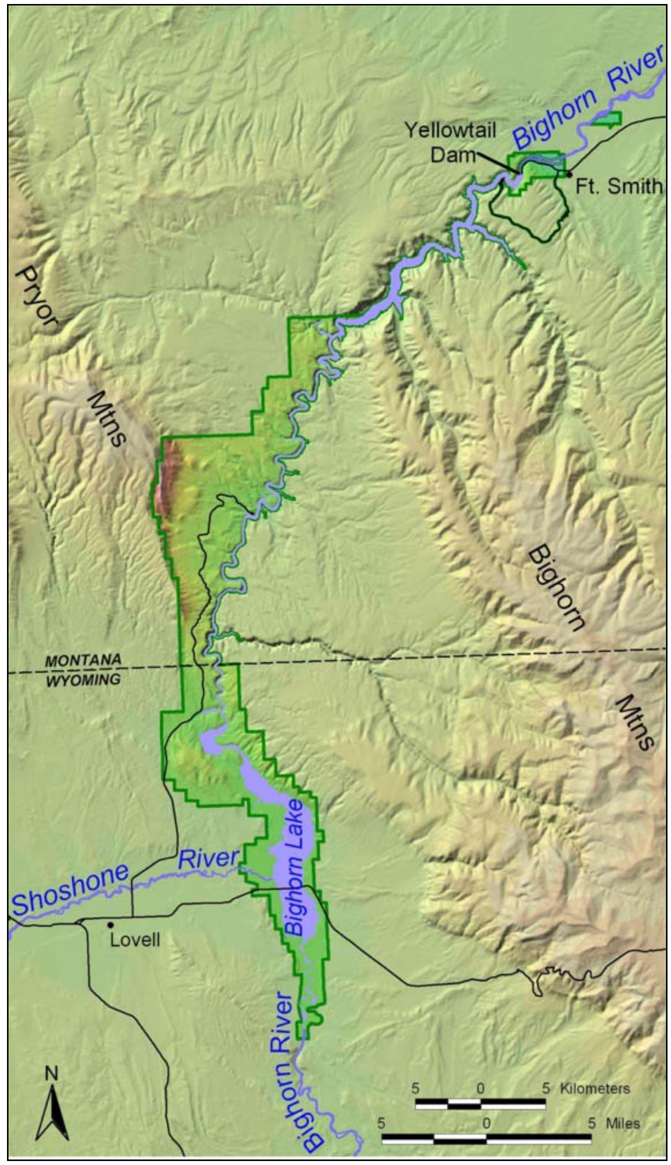

Figure I.3: Bighorn Canyon National Recreation Area.

The Bighorn and Pryor Mountains affect weather patterns in the park, where temperature extremes range from over 100°F (38 °C) to –15°F (-26 °C). The climate of Bighorn Canyon's intermountain xeriscapes is semiarid and cool; winters are cold and summers are hot. Average annual precipitation is less than 15 inches (38 cm), though a large precipitation gradient separates the dry southern end of BICA from the wetter northern end. Most of the precipitation comes—relatively evenly distributed—in fall, winter, and spring.

Yellowtail Dam, operated by the Bureau of Reclamation and located near the northern edge of the park, dominates Bighorn Canyon's hydrology and aquatic resources. The Bighorn and Shoshone Rivers, and other streams that originate in the Pryor and Bighorn Mountains, flow into Bighorn Lake. The water quality of the lake is constantly influenced by upstream agricultural and industrial land use. Concentrations of nutrients, sediments, and total dissolved solids generally are high.

Table I.1: Overview of the parks of the GRYN (NPS n/a).

	BICA	GRTE	YELL
Year of creation	1966	1929	1872
2002 visitation (millions)	0.18	2.6	3.0
Land area managed by park in millions of acres (ha)	0.12 (0.05)	0.31 (0.13)	2.2 (0.89)
Elevation range in feet (m)	3,600 to 4,500 (1,100 to 1,400)	6,400 to nearly 14,000 (2,000 to 4,300)	5,200 to over 11,000 (1,600 to 3,400)
Precipitation range in inches (cm)	5 to 14 (13 to 26)	15 to 31 (38 to 79)	10 to 80 (25 to 203)

The vegetation in BICA, as dictated by elevation, aspect, and drainage characteristics, is chiefly juniper/mountain mahogany woodlands. Other major vegetative communities in BICA include coniferous woodlands, desert shrublands, sagebrush steppe, grasslands, riparian woodlands, and ponderosa pine savannah (Knight et al. 1987). Moving away from the highlands, lush riparian areas along streams in and near the mountains give way to greasewood and other alkali-tolerant plants. Juniper woodlands cover portions of the park that have shallow, coarse-textured sites on fractured bedrock (Wight and Fisser 1968). Non-native species present a significant management challenge, particularly in riparian regions.

Both cold and warm water fish species live in Bighorn Lake, which is managed for recreational sport fishing by the Montana Department of Fish, Wildlife and the Wyoming Game and Fish Department.

This region supports a great variety of wildlife species, many of which move from the mountains into the sagebrush semidesert during the winter. Larger mammals include bighorn sheep, mule deer, wild horses, pronghorn antelope, black bear, coyote, mountain lion, and bobcat. Smaller species include bats, Wyoming ground squirrel, deer mouse, whitetail jackrabbit, and porcupine. Desert and riparian habitats in BICA support diverse reptile and amphibian populations, including sagebrush lizard, horned lizard, and prairie rattlesnake.

The sheer-walled canyons and diverse topography in Bighorn Canyon provide important habitat for raptors, including Swainson's hawk, ferruginous hawk, rough-legged hawk, red-tailed hawk, marsh hawk, prairie falcon, peregrine falcon, great horned owl, and bald eagles. Hundreds of songbirds and other bird species have been documented in Bighorn Canyon. This region also is important to breeding and resting migrating waterfowl. Mallards, pintails, green-winged teal, and gadwalls are most common. Canada geese are locally important. Although less and less common, sage grouse are the most abundant upland game bird.

2. GRAND TETON NATIONAL PARK

Grand Teton National Park (Figure I.4) was established in 1929. The park's purpose, as stated more recently in the 1976 Master Plan, is to "protect the scenic and geological values of the Teton Range and Jackson Hole, and to perpetuate the Park's indigenous plant and animal life."

Grand Teton National Park also administers the 23,777-acre (9,622 ha) John D. Rockefeller, Jr. Memorial Parkway, a symbolic parkway from West Thumb of YELL to the south entrance of GRTE, established in 1972. The parkway commemorates the many significant contributions of John D. Rockefeller, Jr. to the cause of conservation and calls for the area to be managed for the conservation of its scenery and the natural and historical resources. For the purposes of this report, JODR is considered part of Grand Teton.

GRTE is famous for the high-alpine scenery of the Teton Range, including the 13,770-foot

(4,200 m) Grand Teton, which rises a mile above the floor of the Jackson Hole Valley. Eleven other peaks in the Teton Range also rise above 12,000 feet (3,700 m). About eight million years ago, the ancestral Teton Range, the core of which is metamorphic gneisses, schists, and igneous rocks, was fractured along the north-south Teton Fault, resulting in the steep escarpment along the east face of the Teton Range. Subsequent extensive and repetitive glacial activity has been responsible for the present rugged form of the Teton Range and its canyons.

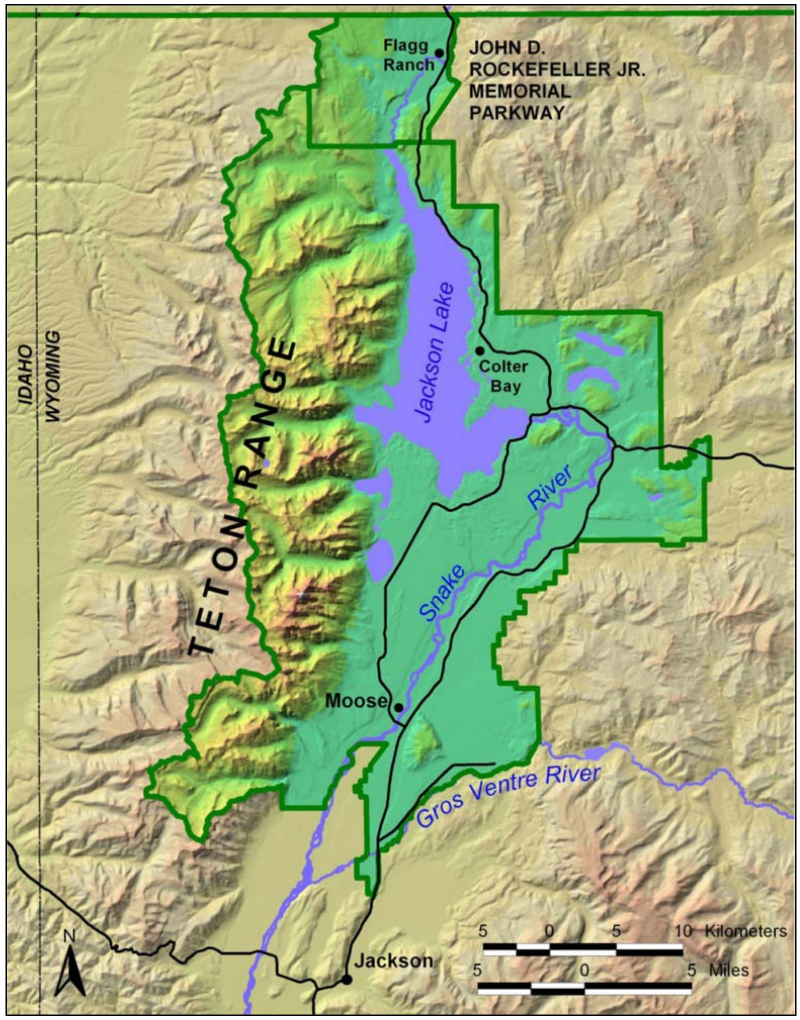

Figure I.4: Grand Teton National Park.

Perennial glaciers and ice fields still occupy protected recesses within the Teton Range. Average snowfall in the park is 191 inches (485 cm), but varies with elevation and location east or west of the Teton Range crest. The climate is generally semiarid with highs approaching 100^{o}F (38 ^{o}C) and an extreme recorded low of –46^{o}F (–43^{o}C). The large variations in elevation, soil types, precipitation, and temperature result in a variety of habitat types and, thus, biodiversity. Over 900 flowering plants, for example, are known to be present in GRTE (NPS n/a2).

As in BICA, several nonconforming uses occur within GRTE boundaries, each causing special management concerns and requiring extensive interagency cooperation. The Jackson Hole airport, for example, is the only commercial airport within a national park and requires NPS cooperation with the Federal Aviation Authority. Grand Teton contains Jackson Lake Reservoir, operated by the Bureau of Reclamation, which retains exclusive control of the flow and utilization of water in the reservoir, except for waters reserved for Snake River fisheries. Elk hunting, managed by the state of Wyoming, is allowed in designated portions of the park. Local elk and bison herds are infected with brucellosis, which creates a major management issue since permittees graze and trail domestic livestock on 24,792 acres (10,033 ha) of the park.

All mammals believed to be present immediately prior to European settlement currently occur in the park. Some of the more common mammals are bison, moose, elk, mule deer, pronghorn antelope, black bears, coyotes, marmots, Uinta ground squirrels, and pikas. Other mammals that are less commonly seen include the grizzly bear, gray wolf, wolverine, river otter, mountain lion, and beaver.

Approximately ten percent of Grand Teton National Park is covered by surface water. The park holds over 100 alpine lakes, ranging in size from one (0.4 ha) to 60 acres (24 ha), many lying above 9,000-feet (2,700 m) elevation. All surface and groundwater in the park drains into the Snake River. The National Park Service and Wyoming Game and Fish Department cooperatively manage fisheries within the park. Several lakes are stocked with fish (one non-native, in Jackson Lake) as part of a sport-fisheries program. Twenty-three species of fish have been documented in Grand Teton. The cutthroat trout, the only trout native to the park, is part of a morphologically distinct group of cutthroat trout found only in the Snake River in the Jackson Hole area.

More than 1,000 species of vascular plants (over 100 of which are non-native) and hundreds of species of fungi occur within and in the vicinity of Grand Teton National Park. The Snake River floodplain, which dominates the valley floor of the park, is made up of riparian forest (e.g., cottonwood, spruce, willow, and aspen). Terraces rising above the flood plain, primarily covered by sagebrush and grasses, are occasionally interrupted by glacial moraines and buttes. The mountain forests consist mainly of lodgepole pine, Douglas-fir, and aspens at lower elevations, while Engelmann spruce, whitebark pine, and subalpine fir inhabit higher elevations.

Amphibians, reptiles, and birds also abound in Grand Teton. Leopard frog and sagebrush lizard have been documented. Almost 300 species of birds have been observed in the park, including white pelican, great blue heron, trumpeter swan, Canada goose, sandhill crane, golden eagle, bald eagle, sage grouse, common raven, Clark's nutcracker, several species of woodpeckers, and a variety of songbirds.

3. YELLOWSTONE NATIONAL PARK

In 1872 Yellowstone National Park (Figure I.5) was created as the world's first national park to be a "pleasuring-ground for the benefit and enjoyment of the people" and to "provide for the preservation, from injury or spoilation, of all timber, mineral deposits, natural curiosities, or wonders within said park, and their retention in their natural condition." It was the Yellowstone experience that led to the growth of a national parks system dedicated to the protection of an irreplaceable national heritage, and whereby the federal government was committed to the management of wild lands for park purposes.

That vision of perpetuating Yellowstone's pristine, natural ecosystems—for their inspirational, educational, cultural, and scientific values—remains intact more than a century later. Today Yellowstone makes up a major portion of the Greater Yellowstone Ecosystem, the largest nearly intact ecosystem in the temperate, industrialized world.

Though home to the grizzly bear, wolf, free-ranging herds of bison and elk, and centuries old sites and historic buildings, Yellowstone is primarily famed for its unmatched geothermal resources. Some 500 geysers—nearly two-thirds of those anywhere on Earth—and more than 10,000 hot springs, fumaroles, and mud pots can be found in Yellowstone (Monteith n/a). This vast collection of geothermal features provides a constant reminder of the park's volcanic past and present. Cataclysmic eruptions 2 million, 1.3 million, and 630,000 years ago produced the Yellowstone caldera. Magma, located in some places only one to three miles (1.6 to 4.8 km) below the Earth's surface, continues to fuel the hotspot. During the summer of 2003, for example, a geothermal "bulge" was discovered in the floor of Yellowstone Lake. Similarly, surface temperatures in Norris Geyser Basin reached 200°F (93 °C), causing the closure of several trails (NPS 2003a).

Climate and geology heavily influence Yellowstone's five distinct vegetation zones. Temperature and precipitation strongly affect the presence and makeup of vegetation communities in the park. Average temperatures at Mammoth Hot Springs range from 9°F (-13°C) in January to

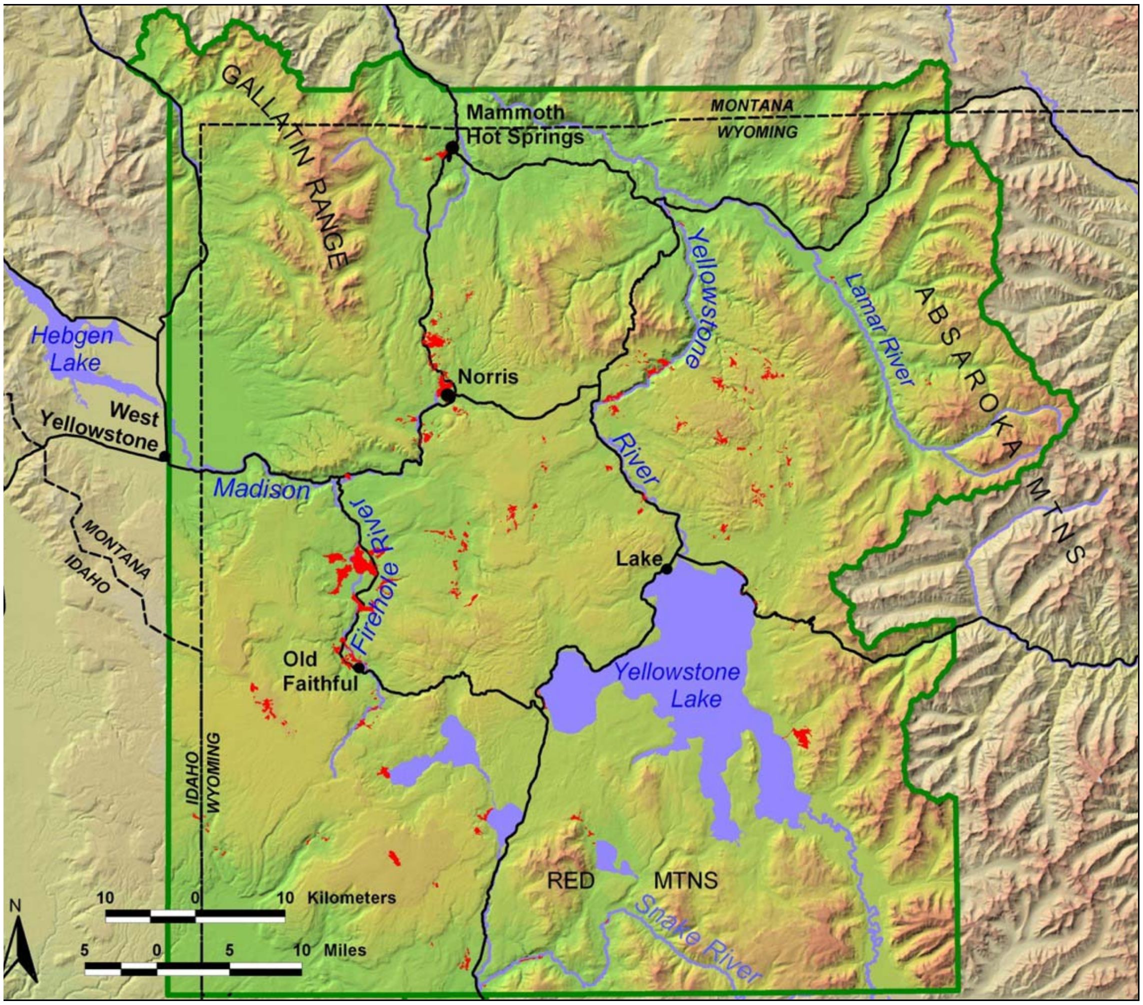

Figure I.5: Yellowstone National Park. Note that geothermal areas are highlighted in red.

80°F (27°C) in July. Temperatures can vary widely, a major stress to flora and fauna. The record high temperature in the park was 98°F (37°C, Lamar in 1936), with a record low of -66°F (-54°C, Madison in 1933). Precipitation also ranges widely, from ten inches (25 cm) at the north boundary to 80 inches (203 cm) in the southwest corner (NPS n/a2). While summer thundershowers can be frequent, winter brings the park's primary source of precipitation: heavy accumulations of snow.

Along with climate, elevation, soil type, and aspect also strongly affect vegetation communities. Most of the park is above 7500 feet (2,300 m) in elevation. Much of the vegetation is typified by forested volcanic plateaus, surrounded by the Absaroka Mountains on the east, the Gallatin Range to the northwest, and the Teton Range to the southwest. Four of the five vegetation zones are underlain by bedrock of volcanic origin and generally support forests dominated by lodgepole pine, Engelmann spruce, subalpine fir, or whitebark pine interspersed with subalpine meadows or alpine tundra above timberline.

A lower elevation vegetation zone, underlain by glacial debris of volcanic and sedimentary composition, provides critical winter range for elk, bison, and other ungulates. Yellowstone's Northern Range, located primarily along the Yellowstone and Lamar River valleys in the northern portion of the park, makes up the largest portion of this low-elevation zone. The zone is dry, dominated by sagebrush steppe and grasslands, is bordered by Douglas-fir, and is highly susceptible to exotic plant invasion relative to other vegetation zones in the park (Rew et al. 2003).

The park watersheds drain into the Yellowstone and Madison Rivers east of the Continental Divide, and into the Snake River on the west. Yellowstone Lake is the most prominent lake in the park with a surface area of 136 square miles (352 square kilometers). Yellowstone hosts a diversity of aquatic life within its pristine waters, including the largest natural cutthroat trout population in the world. Those native cutthroats, which serve as the base food source of an entire food web that culminates with grizzly bears and bald eagles, are under threat from non-native lake trout and whirling disease.

Yellowstone retains the full suite of ungulate and predator populations that existed before European settlement. Ungulate species include elk, bison, mule deer, pronghorn, bighorn sheep, and moose. Mountain goats are not believed to be native to the park but have been observed with increasing frequency along the park's northern boundary. Predators include grizzly bears, mountain lions, gray wolves, lynx, wolverine, red fox, and coyotes. One hundred forty-eight bird species have been documented to nest in Yellowstone, many of which migrate to Mexico and Central and South America for the winter. These species include Canada geese, common ravens, blue grouse, gray jays, red-breasted nuthatch, and American dippers.

B. WHY UNDERTAKE AN INVENTORY AND MONITORING PROGRAM?

NPS's overall mission is "to conserve unimpaired the natural and cultural resources and values of the national park system for the enjoyment of this and future generations" (NPS 2000). Inventory and monitoring (I&M) programs play a key role in achieving that mission.

Assessing long-term ecological health is the fundamental goal of the NPS I&M program. Every part of the program—inventory surveys, conceptual modeling, selection of vital signs, monitoring—is directed toward achieving that fundamental goal.

1. GRYN MONITORING PROGRAM BENEFICIARIES AND TARGET AUDIENCES

The I&M program has many beneficiaries. Foremost are park resource managers, who need the ability to (1) detect significant change in resource condition and (2) evaluate resource response to management actions.

Secondarily, long-term monitoring will provide park scientists, as well as those from academia and the private sector, with fundamental knowledge for understanding park ecosystems. Similarly, effective data sharing will aid in public education. By providing park interpretation programs and the public with information on current studies, management decisions, and trends captured by monitoring programs, the Network hopes to increase public awareness of park activities as well as the state of the natural resources.

More broadly, the monitoring program will help protect important, publicly owned resources at GRYN parks or, in other words, help protect the public trust. The ultimate human beneficiary for NPS monitoring programs is the American public.

2. I&M AS A BASIS FOR ASSESSING LONG-TERM ECOLOGICAL HEALTH

To assess, manage, and protect ecosystem health, NPS must understand the conditions of the natural and cultural features it manages. The first step in gaining this understanding is conducting **inventories—point in time surveys to determine location or condition of a biotic or abiotic resource.** Inventory may involve both the compilation of existing information and the acquisition of new information.

A long-term monitoring program builds on original inventory work through ongoing resource study, observation, measurement, and analysis. Long-term monitoring provides an excellent means of assessing long-term ecosystem health. **Monitoring differs from inventory in that it adds the dimension of time, and that its purpose is to detect changes or trends in a resource.** Detection of a change or trend may trigger a management action, or it may generate a new line of inquiry. Monitoring is often done by sampling the same sites over time, and these sites may be a subset of the sites sampled for the initial inventory[1].

The overall purpose of monitoring, then, is to develop broadly based, scientifically sound information on the current status and long-term trends in the health, composition, structure, and function of park ecosystems, as well as the reaction of those ecosystems to management actions. Ulitmately, the use of monitoring information will improve the ability of NPS to make informed decisions and increase the public confidence in resource management.

3. INVENTORY AND MONITORING MANDATES

The GRYN parks are required to monitor natural resources by National Park Service policy, plus a combination of state and federal laws and regulations.

Early Congressional law, following the establishment of Yellowstone National Park, implied the need to monitor natural resources and to ensure that park values would not be impaired. As shown in Table I.2, the National Park Service Organic Act of 1916 clearly set forth resource preservation as a fundamental goal of the Service. By later in the century, historical parks, scenic riverways, recreation areas (such as Bighorn Canyon), and a variety of other designations had been moved under the NPS umbrella. The enabling legislation for some of these units included

Table I.2: Congressional mandates that direct inventorying and monitoring of natural resources (emphasis added).

"...to promote and regulate the use of the Federal areas known as national parks, monuments, and reservations hereinafter specified by such means and measures as conform to the fundamental purposes of the said parks, monuments, and reservations, which purpose is to conserve the scenery and the natural and historic objects and the wild life therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations"	National Park Service Organic Act of 1916
"The Secretary shall undertake a program of inventory and monitoring of National Park System resources to establish baseline information and to provide information on the long-term trends in the condition of the National Park System."	National Parks Omnibus Management Act of 1998 (NPS 1998a)
"The Committee applauds the Service for recognizing that the preservation of the diverse natural elements and the great scenic beauty of America's national parks and other units should be as high a priority in the Service as providing visitor services. A major part of protecting those resources is knowing what they are, where they are, how they interact with their environment and what condition they are in. This involves a serious commitment from the leadership of the National Park Service to insist that the superintendents carry out a systematic, consistent, professional inventory and monitoring program, along with other scientific activities, that is regularly updated to ensure that the Service makes sound resource decisions based on sound scientific data."	NPS 2000

1 More background information can be found at the NPS I&M website at http://www1.nature.nps.gov/im/monitor/index.htm .

consumptive activities, such as hunting, mining, and grazing. In 1970, however, Congressional reinforcement of the Organic Act ensured that all parkland units—regardless of title or designation—were united by the common purpose of resource preservation.

Both in 1998 and 2000, Congress gave NPS explicit direction to inventory and monitor the natural resources under its charge. The 2000 directive shown in Table I.2 comes from appropriations language for the Natural Resource Challenge, the key mandate driving the NPS Inventory and Monitoring Program. First articulated in 1999, the Natural Resource Challenge is a Congressional action plan that outlines numerous improvements needed in natural resource stewardship (NPS 1999). The Challenge requires that NPS managers know the condition of natural resources under their stewardship, and monitor long-term trends in those resources to conserve park resources unimpaired for future generations. From this Congressional direction, the Service established policy mandating I&M programs:

> *"Natural systems in the national park system, and the human influences upon them, will be monitored to detect change. The Service will use the results of monitoring and research to understand the detected change and to develop appropriate management actions"*
> *(NPS 2001a).*

More than a dozen other pieces of federal legislation and Executive Orders influence the NPS Inventory and Monitoring Program. These Acts range broadly in time and scope, as shown in Table I.3. The Geothermal Steam Act (1970) is particularly notable. As part of a preservation goal, the Act explicitly directs the Department of Interior to monitor significant NPS thermal features. Specific lists of parks with thermal features are provided, with a declaration for Yellowstone that "the entire park unit is listed as a significant thermal feature". A more detailed look at legislation driving the National Park Service's I&M Program can be found in Appendix I.

Along with the Service-wide mandates just described, enabling legislation (BICA in 1966, GRTE in 1929, JODR in 1972, YELL in 1872) and management plans (BICA [NPS 1994], GRTE [NPS 1995]) and business plans (YELL [NPS 2003b]) for each GRYN park require inventory and monitoring activities by committing each park to follow NPS policies.

Table I.3: Federal legislation and executive orders that influence NPS I&M programs.

- Taylor Grazing Act of 1934,
- Fish and Wildlife Coordination Acts of 1958 and 1980,
- Wilderness Act of 1964,
- National Historic Preservation Act of 1966,
- National Environmental Policy Act of 1969,
- Geothermal Steam Act of 1970,
- Clean Water Act of 1972,
- Endangered Species Act of 1973,
- Migratory Bird Treaty Act of 1974,
- Forest and Rangeland Renewable Resources Planning Acts of 1974 and 1976,
- Mining in the Parks Act of 1976,
- American Indian Religious Freedom Act of 1978,
- Archaeological Resources Protection Act 1979, and
- Federal Caves Resources Protection Act of 1988.
- Executive Orders—for example, 11987: Exotic Organisms; 11988: Floodplain Management; 11990: Protection of Wetlands; 13186: Protection of Migratory Birds

C. I&M PROGRAM TIMELINE AND PEER REVIEW

Vital signs monitoring plans are being created in three phases. In Phase I, background material and conceptual models were prepared to build a foundation for Phase II, the selection and prioritization of vital signs. Phase III entails the detailed design work needed to implement monitoring, including the development of sampling protocols, a statistical sampling design, a plan for data management and analysis, and details on the type and content of various products of the monitoring effort such as reports and websites. Major milestones and timelines for Phases II and III are described in Table I.4. Progress on the GRYN Vital Signs Monitoring Plan (e.g., reports, monitoring atlas, results of inventory) can be accessed on the Network's website (http://www.nature.nps.gov/im/units/gryn/index.shtml). Final approved monitoring plans will be released in September 2005, after which the monitoring programs will be implemented.

Timeline

Table I.4 shows a schedule of activities and milestones completed by the Greater Yellowstone Network during Phase II. Descriptions of the Network's completed activities to create its vital signs list—for example, literature survey, conceptual modeling efforts, on-line polling, and science community workshops—will be detailed in Chapters 2 and 3 of this report. In addition, Chapter 3 presents the Greater Yellowstone Network's final list of vital signs.

Peer review

Throughout the production of this Phase II report, the GRYN has solicited regular peer review on its progress. That review covered both the vital signs proposed and selected, as well as

Table I.4: GRYN Phase II (and beyond) program timeline, milestones, and completed activities.

Phase II Chapter I, II, III	*Identify Vital Sign—Important Indicators of Ecosystem Health*	
	✓ Assemble potential Vital Signs and solicit input on importance value in the Delphi III survey	3/15/03
	✓ Define attributes and criteria to filter and rank candidate vital signs	2/24/03
	✓ Sponsor park workshop to present and solicit input from park managers and staff on planning process and criteria used to select and prioritize Vital Signs. Apply criteria to subset of candidate indicator list for peer review.	3/10-11/03 3/19-20/03
	✓ Finalize criteria and prepare for Vital Signs workshop	4/30/03
	Workshop to develop the first-ever prioritized list of candidate vital signs to be monitored as a means for determining the long-term ecosystem health of the Greater Yellowstone Network.	5/6-9/03
	✓ Break out groups apply the selection criteria from the decision support system to each potential vital sign in their topic area and provide results to the decision support system database.	
	✓ Document comments related to the scoring decisions and identify—but don't solve—break out team member issues regarding list and process	
	Vital sign selection, review, and delivery	
	✓ Technical Planning Committee review of workshop results and selection of proposed vital signs for GRYN	6/17-19/03
	✓ Science Committee peer review of selected vital signs, plus development a strategic process for creating monitoring objectives and sampling design	9/22-24/03
	✓ Submit Phase II report	9/30/03
Phase III Chapter I - XII	*Prepare Chapters V-XII*	
	❑ Development of specific measurable objectives, thresholds, and management actions for each selected vital sign	12/15/04
	❑ Sampling design and protocol development	
	❑ Data Management Plans	
	❑ Prepare implementation and staffing plans	
	❑ Submit complete draft of Monitoring Plan for Peer Review	
	❑ **Implement Final Vital Signs Monitoring Plan**	**9/1/05**

the process the Network employed to make those selections. Peer review has been provided by the Network's Board of Directors, its Technical and Science Committees, and other regional and subject-matter experts. Peer review of the Vital Signs Selection Workshop (to be discussed in Chapter 3), for example, can be found in Appendix II. Peer review of the completed Phase II report by the Science Committee is provided in Chapter III.

D. MONITORING GOALS—FROM GPRA, NPS, AND THE GRYN

The National Park Omnibus Management Act codified into law that all NPS field units write Strategic Plans and Annual Performance Plans consistent with the 1993 Government Performance and Results Act (GPRA). GPRA seeks to make federal agencies more accountable to citizenry for the money the agencies spend and the results they achieve. The Act requires that agencies think strategically, plus set, measure, and report on goals annually.

Following GPRA guidance, the NPS Strategic Plan for 2001-2005 (NPS 2001b) sets goals in four categories:

- *Category I:* Preserve Park Resources
- *Category II:* Provide for the Public Enjoyment and Visitor Experience of Parks
- *Category III:* Strengthen and Preserve Natural and Cultural Resources and Enhance Recreational Opportunities Managed by Partners
- *Category IV:* Ensure Organizational Effectiveness.

Category goals are further broken down by time frame into Mission Goals (continue indefinitely), Long-term Goals (five years in duration), and Annual Goals (one year in duration).

Each park is responsible for responding to the overall NPS GPRA goals (e.g., creating Strategic Plans, Annual Performance Plans, and Annual Performance Reports). Local plans, then, are a blend of national and local missions and goals. All three of the parks in the GRYN have prepared five-year Strategic Plans and annually prepare a Performance Plan that tiers to the Service performance goals.

Category I goals—preserve park resources—reflect the NPS Organic Act mandate "to conserve the scenery and the natural and historic objects and the wildlife therein." Across GRYN parks, Category I goals drive work in many areas, a subset of which is shown below:

- *BICA*—disturbed lands, water quality, museum collections, paleontological resources, and natural/cultural resource inventories;
- *GRTE*—exotic plant species, native species of special concern, wildlife research and monitoring, wilderness designation, resource inventories, historical research baselines; and
- *YELL*—geothermal features, winter habitat, wildland fire, exotic plant species, threatened and endangered species, air quality, water quality, museum collections, and historical research baselines.

A full listing of GPRA Category I goals for each GRYN park can be found in Appendix I. Table I.5 summarizes, by park, the number of the Long-term, Category I goals. The completion of Phase II, selection and approval of Vital Signs, accomplishes GPRA goal Ib.3.

NPS has five major, long-term, Service-wide goals for the Vital Signs Monitoring Program (NPS n/a4). All 32 networks must address these goals (Table I.6) as they plan, design, and implement integrated natural resource monitoring. By accomplishing these goals, networks will help park managers, scientists, and the general public use sound science to make and understand resource management decisions.

A primary goal of the GRYN Program is that the GRYN Vital Signs Monitoring Program

Table I.5: Number of long-term goals enumerated for each park under the GPRA Category 1 Goal— Preserve Park Resources.

Category I Goal:		BICA	GRTE	YELL
Preserve Park Resources	**Mission Goal Ia.** Natural and cultural resources and associated values are protected, restored, and maintained in good condition and managed within their broader ecosystem and cultural context.	2	5	8
	Mission Goal Ib. The National Park Service contributes to knowledge about natural and cultural resources and associated values: management decisions about resources and visitors are based on adequate scholarly and scientific information *(includes vital signs monitoring as goal Ib3).*	2	3	1

become intimately integrated into park programs. The GRYN has, thus, crafted three corollary goals in support of the Service-wide monitoring goals. These corollaries—or extensions to the Service goals—are also shown in Table I.6.

Table I.6: NPS Service-wide I&M goals and GRYN corollary goals.

NPS

- Determine status and trends in selected indicators of the condition of park ecosystems to allow managers to make better-informed decisions and to work more effectively with other agencies and individuals for the benefit of park resources.
- Provide early warning of abnormal conditions of selected resources to help develop effective mitigation measures and reduce costs of management.
- Provide data to better understand the dynamic nature and condition of park ecosystems and to provide reference points for comparisons with other altered environments.
- Provide data to meet certain legal and Congressional mandates related to natural resource protection and visitor enjoyment.
- Provide a means of measuring progress towards performance goals.

GRYN

- Determine and monitor the status, trends and magnitude of selected ecosystem drivers and stressors currently or potentially affecting park resources to support sound management decisions, the protection of key resources, and the scientific evaluation and interpretation of ecosystem change.
- Monitor the status and trends of selected species and communities (both plant and animal) of concern that respond to ecosystem stressors and drivers to help support sound management decision, protect resources, and meet GPRA goals.
- Determine indicators of ecosystem resistance and resilience to disturbance and monitor the status and trends in these indicators to avoid crossing thresholds of human-caused ecosystem change.

E. GRYN RESOURCES AT RISK

Although the parklands of the GRYN are large and may seem, superficially, undisturbed, they face many threats. Overuse, development, invasive species, and habitat fragmentation are lead concerns, along with threats to endangered species, air quality, water quality, and natural quiet. In this section, GRYN resources at risk are divided into three subcategories: (1) threatened or endangered species, (2) aquatic resources, and (3) others.

1. THREATENED AND ENDANGERED SPECIES

NPS units provide some of the most secure habitat for long-term viability of numerous threatened and endangered (T&E) species[2]. The Endangered Species Act (ESA) (1973) requires that the Service conserve T&E species and their critical habitats. This responsibility extends to protecting not only federal candidates, but state-listed and state-candidate species as well (the GRYN currently has no state-listed or state candidate species).

Four species that inhabit the GRYN are listed as threatened or endangered under the ESA, as shown in Table I.7. NPS programs associated with each species are briefly described below.

Gray Wolves (*Canis lupus)*—Endangered, Non-essential, Experimental Population

Table I.7: Known presence of T&E species in GRYN parks.

	Bighorn Canyon	Grand Teton	Yellowstone
Endangered			
Gray wolf (non-essential, experimental)		X	X
Threatened			
Bald eagle	X	X	X
Canada lynx		?	X
Grizzly bear		X	X

Although listed as a non-essential (i.e., to the continued existence of the species), experimental species under the final United States Fish and Wildlife Service (USFWS 1994) ruling, national parks are directed to manage wolves as an endangered species, which requires efforts to determine numbers, population trends, and threats to the species. In Yellowstone, wolves have been monitored continuously, usually via radio collaring and tracking, since they were reintroduced in 1995 and 1996 (Smith and Phillips 1996). The monitoring considers primarily population dynamics (e.g., number of packs, reproduction, mortality, movements, habitat use, genetic diversity, and disease) and predator-prey interactions. A wolf report is published yearly (USFWS n/a). Also, a collaborative effort with the United States Geological Survey (USGS) and the Wildlife Conservation Society (WCS) monitors the interaction between wolves, cougars, and bears.

After their 70-year absence from Jackson Hole, gray wolves returned to Grand Teton National Park in the fall of 1998, when two groups from the Yellowstone reintroduction appeared. The wolves ranged widely over the Park, and a monitoring program—primarily in the form of weekly aerial telemetry flights—was established to determine their status and movements. Park staff assists the USFWS in their regional radio-collaring efforts. Denning activities and wolf kills are also monitored.

Bald Eagle (*Haliaeetus leucocephalus*)—Threatened

The bald eagle is one of the greatest success stories of the ESA. In the late 1700's, 100,000 nesting pairs of bald eagles were thought to exist in the lower-48 states. By 1963, that number had plummeted to 417 (USFWS 1999). Under the 1973 ESA (and its predecessor, the Endangered Species Preservation Act of 1966), the bald eagle was listed as endangered in 43 states, including Idaho, Montana, and Wyoming. Remediation activities began, most importantly the banning of the organochlorine pesticide DDT that caused egg-thinning and subsequent breeding

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[2] *threatened:* an animal or plant likely to become endangered within the foreseeable future throughout all or a significant portion of its range; *endangered:* an animal or plant in danger of extinction within the foreseeable future throughout all or a significant portion of its range.

failures.

In 1995, the USFWS downlisted the bald eagle from endangered to threatened across the USA, including those that inhabit the GRYN. Recovery objectives for the Greater Yellowstone Ecosystem had been met as of 1989; 31 eagle nests produced 24 eaglets in 2002 (NPS 2003c). Across the lower-48 states today, almost 6,000 nesting pairs of bald eagles are estimated to exist (USFWS 1999).

Yellowstone and Grand Teton are part of the Greater Yellowstone Recovery Area for bald eagles. Working in partnership with the Greater Yellowstone Bald Eagle Working Group, the parks have annually monitored bald eagle population, territorial occupancy, and nest productivity since 1987(McEneaney 2002). In 2001, along with monitoring historic bald eagle territories, helicopter surveys were conducted to locate new bald eagle nests that may be inaccessible or difficult to locate by foot, vehicle, or boat.

Canada Lynx (*Lynx canadensis)*—Threatened

In April 2000, the USFWS listed the Canada lynx as a threatened species under the ESA. Threats to the Canada lynx include certain types of forest management practices and fire suppression efforts that reduce the amount of understory vegetation in forests. Removal of understory vegetation may impact the capability of forests to support snowshoe hares, the primary prey of lynx. Additional threats include loss of connectivity between isolated ecosystems supporting lynx; incidental mortality during otherwise lawful trapping, hunting and snaring; and suburban development encroaching on wildlands (USFWS 2003).

Following the National Lynx Detection Protocol, the presence and distribution of the lynx in YELL is currently being documented using snow-tracking surveys conducted from the ground (McKelvey et al. 1999) and airplanes (Golden 1993), in addition to camera stations (Kucera 1995) and hair-snare surveys (McKelvey et al. 1999). In 2003, the Carnivore Conservation Genetics Laboratory at the University of Montana at Missoula confirmed a female Canada lynx and her kitten in the central portion of Yellowstone National Park using DNA evidence (NPS 2003c).

GRTE has completed a three-year study in collaboration with the Wildlife Conservation Society to determine (a) the status of lynx in the park, and (b) activity of their primary prey, snowshoe hares. Results from these efforts will provide information for the determination of coarse-scale habitat affinities, and ultimately what role Grand Teton plays in the overall conservation of lynx.

Grizzly Bear (*Ursus arctos horribilis*)—Threatened

Grizzly bears are today isolated to a small portion of their range prior to European settlement, including the Greater Yellowstone Ecosystem (GYE). The bear has been listed as threatened under the ESA since 1975. Threats to grizzly bear populations come primarily from habitat fragmentation and development, and direct bear/human interactions (e.g., highway and railroad mortalities, recreational and resource extraction conflicts, habituation to human food or livestock). These conflicts result in large part because grizzly bears need sizable areas to roam—male grizzlies can have home ranges as large as 2000 square miles (NPS 2003c).

Grizzly bears have been monitored continuously in the Greater Yellowstone Ecosystem since the Interagency Grizzly Bear Study Team[3] (IGBST) was formed in 1973. Their work involves collecting information on bear demography, habitat use, important food sources, and relationships with human activities. The team is made up of several scientists who work officially for the team, as well as biologists from the numerous land and wildlife management jurisdictions in the ecosystem.

[3] Made up of the United States Geological Survey—Biological Resources Division, National Park Service, US Fish and Wildlife Service, US Forest Service, and since 1974 the states of Idaho, Montana, and Wyoming.

Grizzly bear recovery appears to be on a positive trajectory in the Greater Yellowstone Ecosystem. In 1993, the USFWS published a Grizzly Bear Recovery Plan, which included several demographic recovery targets that must be achieved for a recovered grizzly bear population (USFWS 1993). All recovery targets are currently being met (USFS 2003). Similarly, Schwartz et al. (2002), who documented the distribution of grizzly bears in the GYE from 1990 to 2000, describe an increase in occupied habitat of 48% and 34% compared with the 1970's and 1980's, respectively.

Based on such positive trends, in March 2003 the Interagency Conservation Strategy Team[4] published the Final Conservation Strategy for the Grizzly Bear in the Yellowstone Ecosystem (USFS 2003). The Conservation Strategy describes how grizzlies will be managed in the Greater Yellowstone Ecosystem if and when the population is delisted from its ESA threatened status. The document also describes how state and federal agencies will cooperate to manage and monitor the recovery of the bears beyond delisting.

Current and historic monitoring of grizzly bears includes the number and distribution of females with cubs (Knight et al. 1995; IGBST 1998, 1999); mortality (Gunther et al. 1997; Mattson et al. 1992a); modeling population trend (Eberhardt et al. 1994; Eberhardt 1995); and genetic diversity (Waits et al. 1998). Habitat monitoring includes habitat effectiveness; winter-killed ungulate carcass availability (Green et al. 1997; Mattson and Knight 1992; IGBST 1998); cutthroat trout spawning and associated bear use (Andrascik 1992; Olliff 1992; Rienhart et al. 1995); army cutworm moth abundance (Mattson and Reinhart 1991; French et al. 1994); whitebark pine cone production (Knight et al. 1997); and white pine blister rust infection (Kendall and Arno 1990).

[4] Made up of NPS, USFS, USFWS, IGBST, Idaho Department of Fish and Game, Montana Fish, Wildlife & Parks, and the Wyoming Department of Game and Fish.

2. Threats to Aquatic Resources

Aquatic resources across the Greater Yellowstone Network face numerous and varied threats, including climate change, atmospheric deposition, altered hydrology, mining, agriculture, pollution from boats, non-native species, grazing (livestock and native ungulates), erosion, leaking underground storage tanks, improper sewage plant or drain field operations, and storm water runoff. Water quality monitoring to assess the effects of these threats has been underway for over 50 years, though not as a coordinated, comprehensive program focused on ecosystem health. Each park, for example, performs some level of water quality monitoring as part of their annual operation, and the USGS operates several surface water quality monitoring stations within or in the vicinity of each Network park.

Aquatic threats are especially important in the GRYN because of the Outstanding National Resource Waters provision of the Clean Water Act. This provision provides for the maximum protection of our nation's most treasured water bodies. In Wyoming, the state has designated all surface waters located within the boundaries of Yellowstone and Grand Teton National Parks as Class 1—Outstanding Aquatic Resources—a designation that corresponds with ONRW designation.

Threatened aquatic resources may be afforded special protection under federal or state guidelines. Section 303(d) of the federal Clean Water Act, for example, requires the parks to comply with federal or state assessments of waters that may be impaired or threatened, and to assist states in the development of water quality improvement strategies (e.g., Total Maximum Daily Loads or TMDLs). Montana and Wyoming have identified several 303(d) impaired waterways in Grand Teton, Yellowstone, and Bighorn Canyon (see the monitoring atlas in Appendix III for a map showing GRYN 303(d) streams).

Threats to aquatic resources in the GRYN can be broadly lumped into three categories: physical, chemical, and biotic. Physical threats include altered flow characteristics because of dams (e.g., Bighorn Lake and Jackson Lake), irrigation withdrawal, and flood plain development (e.g., rip rap along the Snake River to protect homes). Changes in natural surface water flows disrupt fish migration and spawning, off-stream rearing habitat for juvenile fish, nutrient and seed dispersal via sediment transport, aquifer and wetland replenishment, waterfowl habitat, and natural temperature regimes. Reese Creek is on the 2002 Montana Department of Environmental Quality (MTDEQ) 303(d) list because it can only partially support aquatic life and cold-water fisheries due to dewatering and flow alterations. Crooked Creek, an intermittent tributary to Bighorn River is also on Montana's 303(d) list (although outside the park boundary) due to bank erosion and habitat alterations resulting from agriculture and grazing. A complete list of Network streams listed under section 303(d) of the Clean Water Act can be found in Appendix III.

Chemical threats to aquatic resources come from many fronts. Unprotected mine tailings can release acid and heavy metal leachates into surface waters. Just prior to entering Yellowstone near the northeast entrance, for example, Soda Butte Creek—on Montana's 303(d) list—runs along an estimated 150,000 cubic yards of mine waste containing arsenic, copper, iron, lead, and zinc. In 1950, an impoundment failure washed toxic material more than 15 miles (24 km) downstream into the park. Reduced invertebrate populations and elevated levels of copper in fish tissue are still evident 50 years later. Acidification can also be a threat to remote alpine lakes having low acid-neutralizing capacity. This threat comes not from leachate, but instead from atmospheric deposition of nitrogen and sulfur compounds.

Other land-use and human activities also affect water quality. Bighorn Canyon, hydrologically, sits at the receiving end of an intensely industrial and agricultural basin, which includes such activities as oil, gas, and row crop production (sugar beets, corn, hay, and barley), bentonite mining, and livestock grazing. Salts, pesticides, nutrients, and fecal coliform thus pollute rivers and streams in the Bighorn Basin. The Shoshone River—on Wyoming's 303(d) list—from its confluence with Bighorn Lake upstream to an undetermined distance exceeds state standards related to fecal coliform contamination. The Bighorn River from Yellowtail Dam to the Crow Indian Reservation Boundary is on Montana's 303(d) list due to nutrient loading.

Exotic species and bacterial pollution threaten biotic aquatic resources across the Network, as well. Whirling disease, for example, threatens trout in all three parks. Lake trout in Yellowstone Lake further threaten the native cutthroat trout population. New Zealand mud snails, a recent invasive to Yellowstone and Grand Teton, may directly affect aquatic invertebrates, and therefore trout and other species. Waterway contamination from fecal coliforms also threatens Network waterways. Presence of these bacterial species, including strains of *Escherichia coli*, may be a sign of degraded water quality and an indication contamination from human sewage or animal waste.

3. OTHER THREATENED RESOURCES

Beyond those already mentioned, numerous other issues threaten GRYN parks. Some of the threats occur across all parks, such as habitat loss, detriments to air and water quality, invasive species, human development and use, and lack of information on less visible and less charismatic species. Table I.8 lists threats to GRYN parks, broken down into three broad ecologic domains: atmospheric, terrestrial, and geologic. Threats to water quality were summarized in the text above.

F. PAST AND PRESENT NATURAL RESOURCE MONITORING

GRYN monitoring for assessing ecosystem health will officially begin following acceptance of the Network's monitoring plan in September 2005 (some pilot projects might start following peer review). Though not coordinated into a holistic, long-term program, past and ongoing monitoring efforts will provide a valuable base for the Vital Signs Monitoring Program. In some cases, these efforts will be incorporated directly into the Network's plan; in other cases they will serve as a valuable repository of information on past ecological conditions.

Table I.9 provides a summary of past and present monitoring programs across the three GRYN parks, split out under three ecological domains. To date, almost 200 park projects have been initiated that include some aspect of multi-year study, observation, measurement, and analysis to determine the condition of a biotic or abiotic resource.

Table I.9 reveals the uneven distribution of past and present monitoring efforts, both across ecological domains and across Network parks. Terrestrial studies, for example, have dominated the monitoring work thus far initiated in the GRYN (over 60%). This category includes important ecosystem health issues such as invasive plant and animal species, disease, fire, and human use. The large number of terrestrial studies results in part because researchers—and funding agencies—have had a predisposition to study two other important ecosystem components: wildlife species (especially mammals) and plant communities.

Table I.9 also shows, not surprisingly, that past GRYN monitoring efforts have been most strongly concentrated in Yellowstone Park, with Bighorn Canyon being least studied (as documented to date in the Network's dataset catalog, see Appendix IV). This same observation can be made from Table I.10, which provides a topic area break out for past and present Network monitoring. Note that Table I.10 lumps similar monitoring efforts together. Elk monitoring efforts listed under GRTE, for example, include numerous studies such as population surveys, age-class surveys, hunting statistics, animal disease monitoring, and forage utilization studies.

The full suite of past and present GRYN monitoring efforts, broken out by park and including short study descriptions, status, and contact, can be found in Appendix IV. In the sections that follow, we provide short narrative details on a subset of these efforts, broken out under the same ecological domains used in Tables I.9 and I.10. The descriptions below should be

Table I.8: Major natural resource management issues facing GRYN parks in 2003. Note that aquatic threats are described in section I.E.2.

	BICA	GRTE	YELL
Atmospheric	▪ Local industry, agriculture, and wildland fire effects on air quality ▪ Air quality degradation due to transported emissions	▪ Air quality degradation due to transported emissions ▪ Degradation of natural soundscapes (including the Jackson Hole Airport)	▪ Air quality degradation due to transported emissions ▪ Effects of snowmobile emissions on air quality ▪ Degradation of natural soundscapes due to snowmobiles and other engines
Terrestrial	▪ Juniper woodland dynamics and its effects on bighorn sheep communities (including prescribed fire in non-fire adapted woodlands) ▪ Resource competition between native and non-native species (including bighorn sheep and wild horses) ▪ Fire ▪ Major infestations of Russian olive, salt cedar, knapweeds and halogeton in large portions of the park ▪ Plant communities threatened chiefly by wild horse grazing, cattle trailing, exotic plants, and altered hydrologic regimes	▪ Recreation (including wolf, bear, visitor use, facility development and winter use) ▪ Livestock grazing and trailing ▪ Ungulate populations ▪ Wildlife disease (including brucellosis in elk and bison, chronic wasting disease, West Nile virus, Chlamydia in bighorn sheep) ▪ Blister rust in whitebark pine communities) ▪ Species diversity and abundance (invertebrates, wolf, grizzly and black bears) ▪ Threatened, endangered and sensitive species ▪ Exotic/noxious species (including competition between exotics and natives) ▪ Fire (including prescribed and wildfire) ▪ Excessive erosion ▪ Pollution (including pesticides) ▪ Vertebrate populations (including maintenance of species abundance and diversity) ▪ Land use (including habitat fragmentation) ▪ Disturbed land recovery dynamics	▪ Visitor use (including developments such as facilities and roads and winter use activities) ▪ Brucellosis in bison and possible transmission to cattle ▪ Elk population size and concern about overgrazing, damage to woody and riparian vegetation (including aspen), degradation of streams and bank erosion. ▪ Wolf management (including low elk recruitment rates and movement onto adjacent private and federal lands) ▪ Grizzly and black bear management (including reduction of bear/human conflict, research and monitoring) ▪ Concern for pronghorn populations due to private land development, exotic invasive plant species with low nutritional value, isolation of populations, low recruitment and a reduction in the quantity and quality of winter range) ▪ Low northern bighorn sheep populations (due to Chlamydia epidemic and resource competition with introduced mountain goats ▪ Low moose populations (due to loss of winter spruce-fir habitats from 1988 fires, competitive exclusion by elk, loss of old-growth forests and mortality due to out-of-park hunting) ▪ Effects of snowmobiles on wildlife (including direct mortality and injuries, displacement, harassment and availability of hard-snow surfaces ▪ Major infestations of spotted knapweed, leafy spurge, and other weed species
Geologic	▪ Loss and compaction of cryptogametic crusts ▪ Loss of crystal and agate resources ▪ Slumping of canyon benches ▪ Trail formation ▪ Development of bare areas ▪ Industry (including oil and gas production and bentonite mining)	▪ Oil and gas development ▪ Earthquakes	▪ Lack of microbial inventories ▪ Benefits-sharing between park and companies benefiting from commercial applications of information gathered while researching microbial communities ▪ Threats to geysers (including cold water inflow and hot water outflow) ▪ Cold water diversions ▪ Oil, gas and geothermal exploitation developments near park boundaries ▪ Exotic plant invasions compromising persistence of Ross's bentgrass (endemic to a few geothermal environments within the park) ▪ Potential volcanic eruptions, hydrothermal explosions and earthquakes ▪ Geothermal development outside park

considered highlights of past and present monitoring efforts; we do not cover T&E species, which were described previously, nor many other programs described in Appendix IV. Also, note that while the discussion includes numerous literature references, a comprehensive review is not intended. A literature survey covering almost 400 scientific reports and peer-reviewed journal articles can be found in Appendix V.

Table I.9: Overview of monitoring programs in GRYN parks. Numbers shown reflect past and current monitoring programs documented in Appendix IV.

	BICA	GRTE	YELL	*Totals*
Atmospheric	2	2	3	**7**
Terrestrial	14	30	71	**115**
Aquatic	3	5	23	**31**
Geothermal	0	0	33	**33**
Totals	**19**	**37**	**130**	**186**

1. Atmospheric

No baseline, ongoing, or historic collection of air quality data exists for BICA. Until 1997, climate data for BICA was collected at a manual weather station at Horse Shoe Bend and from an automatic weather station at the historic Ewing-Snell ranch. In 2003, BICA installed a centrally located, remote automated weather station. Data are collected hourly and includes precipitation, wind speed and direction, temperature and relative humidity, fuel temperature and moisture, and atmospheric conditions such as barometric pressure and solar radiation.

Grand Teton and Yellowstone are both designated Class 1 areas under the Clean Air Act. Both operate weather stations capable of measuring meteorological data. YELL assists the NPS-Air Resources Division (NPS-ARD) in measuring pollutant levels, including wet and dry deposition, visibility, and ozone. A wet deposition collector is located at Tower Junction in Yellowstone, and a Clean Air Status and Trends Network (CASTNet) dry deposition monitor is located at Lake. The USGS Synoptic Snow Survey Network has two sample locations in GRTE and four in YELL for the purpose of collecting total integrated snowpack samples at maximum accumulation (NPS-ARD 2002).

The NPS currently has ongoing monitoring of visibility changes at Yellowstone Lake through the Interagency Monitoring of Protected Visual Environments (IMPROVE) Program. IMPROVE is a joint venture between the NPS, EPA, and other state and local agencies that measures changes in visibility, which can be thought of as a measure of cumulative impacts to air quality. A time series of the Yellowstone Lake images can be viewed at the IMPROVE website (IMPROVE n/a).

As of the 2000 GPRA Review, YELL did not meet the NPS GPRA Air Quality goals (GRTE and BICA were not reported); however, YELL did show a significant improvement in number of clear days and sulfate content in precipitation. Threats to visibility and air quality from new and possible future energy development (especially power plants) near all three parks are a concern.

2. Terrestrial

Amphibians and Reptiles

Bighorn Canyon: As of 2001, 16 species of reptiles and amphibians have been reported to occur in BICA, with eight species confirmed during recent inventories (Baum and Peterson 2002). Species considered rare or sensitive, such as the Woodhouse’s toads and northern leopard frogs, were found to occur in Bighorn Canyon.

Table I.10: Overview of principal study topics for past and present monitoring efforts in the GRYN.

	BICA	GRTE		YELL		
Atmos-pheric	▪ Weather stn ▪ Precipitation	▪ Weather station ▪ Ozone		▪ Long-term temperature variability	▪ Air quality (NADP)	▪ Snowpack
Terr-estrial	▪ Floodplain vegetation ▪ Vegetation plot mapping ▪ Breeding bird surveys ▪ Bird count ▪ Mule deer / bighorn sheep / feral horse interactions ▪ Pheasant counts ▪ Wild horse counts and range condition ▪ Bighorn sheep ▪ Bald eagles	▪ Amphibian ▪ Bald eagle ▪ Osprey ▪ Goshawk ▪ Peregrine falcons ▪ Owls ▪ Buteos ▪ Raptors ▪ Breeding birds ▪ Neotropical birds ▪ Sage grouse ▪ Trumpeter swans ▪ Blue herons ▪ Whooping crane ▪ Harlequin ducks ▪ Bighorn sheep ▪ Bison ▪ Elk ▪ Moose ▪ Pronghorn ▪ Mountain goats	▪ Grizzly and black bear ▪ Mountain lion ▪ Wolf ▪ Lynx ▪ Wolverine ▪ Mustelidae and Felidae ▪ Beaver ▪ Small Mammals ▪ Integrated pest management ▪ Fire (including in sage) ▪ Ungulate grazing ▪ Rare plants ▪ Vegetation community ▪ Invasive plants ▪ Tree hazards ▪ Deciduous trees ▪ Whitebark pine ▪ Mtn pine beetle ▪ Backcountry management ▪ Developed areas ▪ Wilderness values	▪ Army Cutworm Moths ▪ Gypsy moth ▪ Mosquitoes ▪ Host race of *Brachypterolus pulicarius* ▪ Amphibian ▪ Breeding bird surveys ▪ Lodgepole pine bird surveys ▪ Bird counts (winter, migratory) ▪ Molly Island colonial nesting ▪ Bald eagle ▪ Osprey ▪ Peregrine falcons ▪ Trumpeter swans ▪ Trace elements from cervids ▪ Ungulate carrion and nutrient cycling ▪ Ungulate grazing ▪ Bison (population, *Brucellosis,* use of winter roads) ▪ Elk	▪ Pronghorn ▪ Mule deer ▪ Bighorn sheep ▪ Mountain goats ▪ Grizzly and black bear (predator/prey, genetics, behavior, population, human impacts…) ▪ Mountain lion ▪ Wolf (predator/prey, stress, population…) ▪ Spawning effects on grizzlies ▪ Lynx ▪ Beaver ▪ Otter ▪ Rare mammals ▪ Spring carcass ▪ Road-killed wildlife ▪ Whitebark pine ▪ Aspen regeneration	▪ Carbon allocation in lodgepole pine ▪ Fire and climate change ▪ Habitat as a biodiversity predictor ▪ Land-cover changes in the Yellowstone and Snake River plains ▪ Sage brush ecology and ungulates ▪ Rare plants ▪ Vascular plant inventory ▪ Exotic plants ▪ Wetlands mapping ▪ Satellite imagery for snowmelt and green up ▪ Human disturbance affect on avian abundance ▪ Backcountry management ▪ Stock site use ▪ Winter recreation effects ▪ Wildlife disease
Aquatic	▪ Creel census reports ▪ Reservoir elevation ▪ Water temp	▪ Snowpack ▪ National Water Quality Assessment ▪ Groundwater	▪ Water quality on five Snake River tributaries ▪ Human backcountry impacts	▪ Gibbon River sediment ▪ Remote tributary flow regimes ▪ Soda Butte Creek water quality ▪ Stream monitoring ▪ Thermophilic insects	▪ Mercury dynamics ▪ Whirling disease ▪ New Zealand mudsnail ▪ Backcountry lakes ▪ YELL Lake lake trout	▪ Angler pressure and success ▪ Water temperature ▪ Macroinvertebrate ▪ Grayling ▪ YELL and westslope cutthroat
Geo-thermal				▪ Fungi from geothermal areas ▪ Selected geothermal areas ▪ Quaternary geology and ecology ▪ Geochemical model of Mammoth HS ▪ Redox chemistry in hot springs ▪ YELL Lake vents: bio/geochemical ▪ Chloride flux	▪ YELL hotspot geodynamics ▪ Caldera crustal deformation ▪ Thermal feature biogeochemistry ▪ Thermal & thermophile feature inventories ▪ Function of hot spring photosynthetic mats ▪ Thermophilic bacteria, viruses, and Protozoa ▪ Fossil pollen / spores	▪ CO2 emissions ▪ Microbial biomarkers ▪ Pilobolus survey ▪ Acid-tolerant grasses ▪ Old Faithful ▪ Thermal feature vandalism ▪ Mining impacts

Grand Teton: In 1992, the park began conducting annual amphibian surveys to provide baseline data on species distributions and demography. Dr. Chuck Peterson of Idaho State University has coordinated amphibian surveys in the park since 1991, documenting four of the six species known for the area listed in Koch and Peterson (1995). The two remaining species—leopard frogs and non-native bullfrogs—have been documented by observations and photographs. Koch and Peterson (1995) list four species of reptiles as present in Grand Teton. It is also believed (Peterson pers. comm.) that one additional species (Great Basin gopher snake) may possibly occur in the southern end of the park.

Yellowstone: Since 1985, the occurrence and distribution of amphibians and reptiles has been documented opportunistically in Yellowstone, generally with funds associated with project compliance (e.g., highway or other construction funding) (Patla and Peterson 2000; Koch and Peterson 1995).

In 2001, the GRYN I&M program initiated a three-year survey of amphibians and reptiles in the network parks to document presence of all amphibian and reptile species, repeat historic surveys, conduct systematic surveys to document species distribution and abundance, and identify critical habitat.

Birds

Decimated by DDT, peregrine falcons were considered extirpated from the Greater Yellowstone Ecosystem by the 1960's. Efforts to reintroduce falcons went on through the early 1980's, with the first verified nesting attempt in Grand Teton occurring in 1987. Since then, at least three territories have become established in Grand Teton. Yellowstone reintroduction has also been successful; in 2002, 20 nesting pairs fledged 35 young. Between 1990 and 1994, BICA, in cooperation with the Bureau of Reclamation and the Peregrine Fund, similarly made efforts to reintroduce falcons. However, recent data on the success of these efforts is minimal. Annual breeding surveys document the distribution and productivity of nesting falcons in GRTE and YELL.

Bighorn Canyon: A bird and mammal inventory for BICA, conducted by the Wyoming Cooperative Fishery and Wildlife Research Unit, and detailing expected habitat-bird species associations within BICA and the Yellowtail Wildlife Habitat Management area, was compiled by Patterson et al. (1985). Bird counts are conducted on a regular basis by the local Audubon Society chapter, which allow for documentation of incidental species presence, while the Wyoming Game and Fish Department (WGF) regularly conducts mid-winter bald eagle surveys that result in sightings of many raptor species. Such efforts have assisted in the formulation of a birding checklist for the Pryor Mountains and Bighorn Canyon (Wolf 1990).

Grand Teton: As a "species of special concern" to the park, great blue herons have been monitored annually in GRTE since 1987. Overall productivity is declining and rockeries are becoming inactive over time. Similarly, sage grouse numbers have declined significantly throughout the West, and the USFWS has been petitioned to list the sage grouse under the ESA. In addition to performing annual breeding ground surveys, Grand Teton, in cooperation with the University of Wyoming, is monitoring current and historical leks and determining seasonal habitat use by sage grouse in the Jackson Hole area.

Trumpeter swans have made a comeback in many areas of the country after being nearly hunted to extinction by the turn of the century. Trumpeter swan populations in the Greater Yellowstone Ecosystem, however, have declined 38% over the last ten years. Concern over this drop has resulted in cooperative monitoring efforts between state and federal agencies. GRTE has participated in these efforts since 1987 and annual surveys for swan occupancy, nesting status, and cygnet survival.

In the late 1960's, Dr. M. L. Cody established a monitoring plan for breeding birds in

Grand Teton to evaluate local, regional, and, to some extent, continental, population trends of birds that breed in the northern Rocky Mountains. This work initiated a long-term monitoring program that is effective in censusing small, terrestrial-foraging species with small territories in differing major vegetation types. Monitoring efforts, by park personnel, local volunteers, WGF staff, and Dr. Cody occurred in 1999, 2000, and 2001 on a variety of sites spanning elevations from 6,000 to 11,000 ft (1,800 to 3,400 m).

Yellowstone: Nesting birds have been monitored on the Molly Islands in the southeast arm of Yellowstone Lake since 1977 for species, number of nests, and nesting success (McEneaney 2002). For over a decade, population, nesting, and productivity data has also been collected for the osprey (McEneaney 2002) and common coot (McEneaney 2002). Trumpeter swan populations and reproduction have been continuously monitored in Yellowstone since 1931 (Wright 1935; Banko 1960; McEneaney 2002).

Mammals

Bighorn Canyon: A mammal inventory for BICA, published in 1985, lists 67 mammal species (Patterson 1985). Two-thirds of these species include documentation ranging from capture/collection to wildlife observation cards; the remainder are included based on known habitat preferences and the presence of such habitats in BICA. The species listed in Anderson et al. (1987) include 66 of the 67 species listed in Patterson (1985); Worthington and Ross (1990) include a species of bat not recorded in the other lists.

Much research has been done regarding the ecology of bighorn sheep, wild horses, and mule deer, including management recommendations (Peters 1991; Coates and Schemnitz 1989; Gudorf 1996; Duncan 1975). Others have documented competitive interactions among these animals (Irby et al. 1994; Schemnitz and Coates 1987; and Kissell et al. 1996). The USGS Biological Resources Division (BRD) is currently collecting data concerning bighorn sheep habitat requirements within BICA, in addition to census data, and the status of horses on the Pryor Mountain Wild Horse Range is monitored continuously by the Bureau of Land Management.

Grand Teton: Prior to 1997, there were no data available on free-ranging, brucellosis-infected populations of bison. GRTE, in cooperation with other federal and local agencies, is gathering information on the frequency and timing of prenatal losses by cows that differ in brucellosis status (i.e., non-infected females and those that vary in “degree” of infection). This data will help improve understanding on the effects of the disease on reproduction and population growth in free-ranging, brucellosis-infected bison. That understanding, in turn, will help point out the differences (if any) in how the disease affects bison and cattle and will play an important role in bison management and the legally mandated livestock grazing program.

Aerial surveys of elk on summer ranges throughout Grand Teton are conducted every three years to arrive at annual population estimates. Summer age and sex classification studies are also conducted. Data gathered from elk harvested in GRTE each fall and winter include: age class and sex of elk killed, time period, permit type, hunt area, and nearest landmark to kill site. These data are added to the interagency Jackson elk database, and then included in the Park's annual report to the Jackson Hole Cooperative Elk Studies Group. The park cooperates and assists with United States Department of Agriculture-Animal and Plant Health Inspection Service, the State of Wyoming, and other agencies during animal disease monitoring programs, specifically as it relates to acquiring needed biological specimens that from harvested elk.

Yellowstone: The Northern Yellowstone Cooperative Wildlife Working Group, comprised of biologists and managers from the NPS, the Montana Department of Fish, Wildlife and Parks, the U.S. Forest Service, and the United States Geologic Survey, has conducted regular ungulate surveys since 1983 on Yellowstone's Northern Range. Monitoring was established to estimate the population size of elk, mule deer, bighorn sheep, mountain goats, and pronghorn and to classify herds as to age, sex, and class. Similarly, biologists from Montana State University (MSU) continue to monitor the abundance, composition, distribution, reproduction, resource selection, and survival of elk in the Madison, Firehole, and Gibbon drainages of YELL (Garrott et al. 2002a, b). In 1996, this monitoring was expanded to quantify predation rates, prey selection, and predation effects of wolves on elk (Jaffe 2001).

Bison abundance has been estimated through visual observations from the ground or through systematic aerial observations almost annually since 1901 (Skinner and Alcorn 1942-1951; Meagher 1973). Classifications of the population to determine age and sex ratios have been conducted sporadically over time (Meagher 1973; Pac and Frey 1991; Gogan et al. 1998; USDA 2000). Monitoring the occurrence of *Brucella abortus* in the bison population (using serology methods) has been conducted on a periodic basis, but has occurred more routinely in recent years due to samples provided by management actions at the park boundary (Tunnicliff and Marsh 1935; Pac and Frey 1991; Aune and Schladweiler 1992; Gogan et al. 1998; Roffe et al. 1999). Animal capture at the park boundary will provide a continual source of samples to monitor serological prevalence of *Brucella* exposure in the bison population (USDA 2000).

Coyote and cougar demographics, spatial relationships, and interactions with other carnivores (particularly wolves) have been monitored on the Yellowstone Northern Range since 1990 (Murphy 1998; Ruth 2001). Fox movement patterns and habitat use have been monitored on the Northern Range since 1996 (Fuhrmann 1998). Beginning in 1998, otter food habits and/or movements in Yellowstone Lake and its tributaries were monitored to assess transport of nutrients contained in feces, particularly nitrogen, from the lake to its tributaries.

Beginning in 2002, the abundance, demographic characteristics, and genetic characteristics of snowshoe hares have been monitored in assorted forest cover types in Yellowstone National Park. Studies of population size and trend among small mammals on the Northern Range were initiated in 1991 (Crabtree et al. 1997).

Flora

Non-native species are a major management issue at all three parks of the Network. At Bighorn Canyon, where populations of noxious weeds have not been well documented, a non-native vascular plant inventory was initiated by the GRYN. Invasive work was conducted in 1997 under the auspices of the Tamarisk Control Project, an interagency project with the

Bighorn National Forest. Grand Teton's exotic plant inventory is ongoing and focuses on five "zones" within the park: (1) developed, (2) right of way, (3) riparian, (4) backcountry, and (5) valley. The presence of new weed species and degree, distribution, and population changes in existing weed infestations are monitored annually. Formal monitoring is also being conducted to evaluate the effects of biological control treatments on specific sites, such as those containing spotted knapweed and dalmation toadflax infestations. In Yellowstone, dalmation toadflax was surveyed and monitored in the Mammoth Hot Springs area in the mid-1970's. Annual monitoring of exotic vegetation along roads and in developed areas began in the early 1990's (Olliff et al. 2001). Monitoring and mapping continue in conjunction with control efforts. Moreover, a four-year inventory (2001-2004) is underway to estimate occurrence, extent, and dynamics of non-indigenous plants in Yellowstone's Northern Range (Rew et al. 2003).

Bighorn Canyon: An unpublished vascular plant species checklist (Heidel and Fertig 2001) documents 733 plant species at BICA and includes 70 species previously unknown in BICA (discovered during rare plant work in 1998 and 1999). An earlier published list includes 656 species (Lichvar et al. 1985). Voucher specimens for most of these species reside in the Park's herbarium or the Rocky Mountain Herbarium at the University of Wyoming. Knight et al. (1987) described and mapped the vegetation ecology of Bighorn Canyon National Recreation Area. Historic monitoring of cushion plant community exclosures and Daubenmire transects in grazed pastures was discontinued in approximately 1996.

Grand Teton: Much of the vegetation species information for Grand Teton comes from Shaw (1976, 1992) and includes both Grand Teton and surrounding non-park areas. Recently, Stuart Markow of the University of Wyoming developed a more accurate checklist of vascular plants occurring within Grand Teton using specimens from several herbaria (e.g., University of Wyoming, GRTE, Teton Science School). The checklist includes records of 894 vouchered species documented within Park boundaries. Also, the Wyoming Natural Diversity Database performed a rare plant survey in 1991-1992 (Marriott 1993).

Yellowstone: Long-term vegetation monitoring of vascular plants and communities has typically been associated with the ungulate exclosures constructed from 1957-62. However, some authors have used repeat photography, rather than site measurements, as a monitoring tool, particularly for aspen and willow communities (Kay 1990; Meagher and Houston 1998). Grassland communities have traditionally been sampled using Parker transects while attempting to convert to a more repeatable and statistically reliable sampling scheme. Houston (1982) provides a discussion of trends across a variety of vegetation communities. Later works of Singer et al. (1994) and Singer (1996) on willows, Singer and

Renkin (1995) on the shrubs in big sagebrush communities, and Coughenour et al. (1996) and Singer (1995) on bunchgrass communities describe methods, additional study sites, and more recent results and interpretations.

Following the fires of 1988, Renkin and Despain (1996) established 15 aspen seedling monitoring sites in various habitats in the northern half of the park. Other long-term aspen monitoring sites have been established to study landscape-level trends in aspen dynamics (Ripple at al. 2001).

Habitat conditions (in terms of vegetation) are quantified at the landscape scale by bear management units. Grizzly bear habitat conditions are monitored annually using the grizzly bear cumulative effects model (CEM) to assess changes in habitat effectiveness as a result of human activity (Mattson et al. in press).

Transects to survey for the presence of blister rust in whitebark pine throughout the park were placed in 1957 and have been monitored as recently as 1995 (Kendall and Keane 2001).

Fire Effects

The National Park Service Fire Effects program, operating in GRTE and YELL, provides scientific information to help evaluate prescribed fire management (NPS 2001c). Four levels of monitoring occur: (1) environmental monitoring (including fire weather, fuels conditions and fire danger rating), (2) fire observation (location, size, cause, ignition point, fuels and vegetation description, and fire behavior), (3) short-term change monitoring (treatments in which immediate or one-time effects are considered), and (4) long-term change monitoring (where multiple treatments and repeated maintenance of conditions are necessary) (Miller 2002). The program helps to detect trends, support adaptive management, and determine whether resource and fuels objectives are being met. At Grand Teton National Park, the fire effects crew maintains a network of permanent vegetation monitoring plots in the park and surrounding Bridger-Teton National Forest. The plots follow protocols outlines in the NPS Fire Monitoring Handbook (NPS 2001c).

Recreation Effects

Recreational impacts to wildlands and overnight backcountry use have been monitored in Yellowstone since backcountry campsites were designated in 1972 (Olliff and Consolo Murphy 2000). Both Grand Teton and Yellowstone employ computerized permit systems that allow ready access to backcountry use statistics (such as number of people, boat, stock, and outfitter use nights) (Oosterhous 2000, Olliff and Consolo Murphy 2000, Olliff and Varley 1993). In Yellowstone, grazing impacts from recreational stock use (both horses and llamas) have been monitored at 56 critical backcountry stock sites for graze utilization and range readiness, since 1989 (USFS 1977; Olliff and Consolo Murphy 2000). Winter recreationalists, including skiers, snowmobilers, snowshoers, and backcountry campers, impact natural resources (Olliff et al. 1999, USDI-NPS 2000) in both GYE parks.

3. AQUATIC

Biotic

Bighorn Canyon: A 1985 inventory of Bighorn Lake and several perennial streams resulted in a list totaling 28 fish species (Redder et al. 1986). The Wyoming Game and Fish Department and the Montana Department of Fish, Wildlife, and Parks occasionally conduct creel censuses on waters within BICA, but these efforts have only documented a slightly larger array of species than listed by Redder et al. (1986). The sturgeon chub was found once during a 1981 survey and has not been recorded since; updates on the abundance of this and other rare and exotic fish are needed. The effects of supersaturation of dissolved gases on the Bighorn River fishery downstream of Yellowtail Dam was documented by Phillips (1987).

Information regarding aquatic species, other than fish, in the rivers and streams of Bighorn Canyon is extremely limited (Jacobs et al. 1996). Informal, unpublished lists of aquatic macroinvertebrates collected from various locations throughout the park during the summer of 1985 identify macroinvertebrates only to genus. However, the Wyoming Department of Environmental Quality (WYDEQ) collected macroinvertebrate samples from Crooked Creek and the Shoshone River within BICA boundaries during the summer of 2001. Unpublished taxonomic lists reside at the WYDEQ Sheridan Field Office. Additional aquatic macroinvertebrate sampling occurred at a limited number of sites in 2002, with results forthcoming.

Grand Teton: Most of the fisheries data for Grand Teton has been collected by the Wyoming Game and Fish Department due to the active maintenance of a sport fishery in the park since the early 1920's. Current park and WGF records list 19 fish as occurring in the park, 12 native and seven non-native (Grand Teton NP 1986; R. Hudelson, pers. comm.). Jackson Lake is stocked with non-native lake trout, and only hatchery-reared, native cutthroat trout are stocked in three additional lakes. The Kelly Warm Springs have maintained non-native aquarium fish (guppies, swordtails, and zebra fish) since the 1960's; however, due to their thermal isolation, the species are not considered a threat to native species.

Yellowstone: NPS staff have conducted an aggressive gillnetting program in Yellowstone Lake since 1995 with the dual purpose of removing exotic lake trout and monitoring lake trout abundance and distribution in the lake. NPS hopes to (1) increase its understanding of lake trout and cutthroat trout spatial, vertical, and seasonal distributions in Yellowstone Lake, (2) determine the age and size structure of the lake trout population, and (3) identify new lake trout spawning areas (Kaeding et al. 1995; Olliff 1995; Keading et al. 1996; Mahony and Olliff 2000; Mahony and Ruzycki 1999). In 1997, 1998, and 2001, Idaho Department of Fish and Game volunteered personnel and equipment to estimate lake trout densities in Yellowstone Lake using hydroacoustic surveys (Maiolie 2001 unpublished data), which park staff have continued in an effort to augment gillnet monitoring (Koel et al. 2002a, Koel et al. 2003). Additionally, much research has focused on native cutthroat trout. Swedish gillnets have been used to sample Yellowstone cutthroat trout in Yellowstone Lake since 1969. Since 1951, fish traps and weirs have been used to monitor the spawning runs of Yellowstone cutthroat trout at Clear Creek (Jones et al. 1988; Koel et al. 2002a).

Spawning cutthroat trout are regularly monitored in Arnica Creek, a tributary on the West Thumb of Yellowstone Lake (Benson 1960), Bridge Creek (Koel et al. 2002), and at LeHardy Rapids on the Yellowstone River. In anticipation of restoring the native westslope cutthroat trout, the NPS and several partners are examining seasonal movement patterns in the North Fork of Fan Creek, the location of the only remaining population of the westslope cutthroat trout that is genetically pure and disease free. This study will also inventory all streams in historic westslope cutthroat trout range for potential restoration sites (Koel et al. 2002a).

After whirling disease was confirmed in the Madison River in 1994, the NPS and the USFWS began a cooperative effort to collect wild salmonids from YELL streams for whirling disease testing. In 1998, whirling disease was discovered in Yellowstone Lake (Hudson and Mahony 2001), which focused research on spawning streams near Yellowstone Lake. These studies include surveys for *Tubifex tubifex* and associated stream substrate and determine the presence or absence of the whirling disease pathogen in adult cutthroat trout in Yellowstone Lake (Koel et al. 2002a; Koel et al. 2002b; Koel et al. 2003).

Several representative fishery stream types were surveyed in the late 1920's and more systematic stream inventories began in the 1960's. By 1990, more than 600 streams had been inventoried (Jones et al. 1990). Long-term monitoring has been less systematic; current stream monitoring objectives include multi-year sampling to detect interannual fish population variability in at least two major recreational stream fisheries annually, and to monitor the health of fish populations at streams affected by road construction (Koel et al. 2002a).

Water Quality

Bighorn Canyon: Shortly after impoundment of the Bighorn River, the Montana Department of Fish, Wildlife, and Parks began to publish—as directed by the Federal Aid in Fish and Wildlife Restoration Acts—a series of Bighorn Lake and Bighorn River post-impoundment studies (Swedburg 1970-1978; Fredenburg 1985). Later, the results of limnological studies on Bighorn Lake and its tributaries were described in Soltero (1971). Wright and Soltero (1973) then described the effects of impoundments on the water quality of the Bighorn River and again summarized limnological studies of Bighorn Lake and the Bighorn River.

In a 1976 USGS publication, Lowry et al. described the water resources of the Bighorn Basin. In 1977, Kent summarized physical, chemical, and biological investigations of Bighorn Lake for the period of 1965-1975. Also in 1977, the Environmental Protection Agency (EPA) reported on Yellowtail Reservoir as part of its National Eutrophication Survey, plus and documented changes in zooplankton species composition in the newly filled lake (Horpestad 1977).

In 1981, Lee and Jones described both water quality and rates of sedimentation in Bighorn Lake. Blanton (1986) published Bureau of Reclamation sedimentation data from a 1982 survey. Riparian vegetation dynamics along the Bighorn River were described by Akashi (1988).

In 1993, the water resources of Bighorn County, Wyoming were described in a USGS Water Investigations Report that detailed much of the stream flow, groundwater, and water use and quality characteristics of the region that influences Bighorn Lake (Plafcan et. al. 1993). In 1994, the Natural Resource Conservation Service (NRCS, previously the Soil Conservation Service) issued a final report and recommendations regarding surface water quality within the Bighorn River Basin and, in 1995, Martin evaluated flood hazards associated with campgrounds in BICA and proposals for sediment management in the Horse Shoe Bend area of the park. In the second half of the 1990s, a Water Resources Management Plan for BICA was published (Jacobs et al. 1996), providing direction for future water-related research and the NPS Water Resources Division provided BICA with a document summarizing relevant surface water quality data as retrieved from six EPA national databases (NPS 1998b).

While there are no regularly monitored groundwater observation wells within the vicinity of BICA, the USGS continues to operate surface water stations along the Greybull, Shoshone, and Bighorn Rivers, collecting both physical and chemical data, and has historically operated surface water stations on both regulated and perennial streams of importance to BICA (e.g., Porcupine Creek and Crooked Creek). Segments of the Bighorn and Shoshone Rivers within BICA boundaries are regularly monitored (from May through October of each year) for fecal coliform levels to assure compliance with EPA and WYDEQ full-body contact recreation water quality standards.

Grand Teton: Funding was obtained in 2001 to conduct a synoptic survey of baseline water-quality parameters in five major tributaries of the Snake River. The baseline data will complement data collected at two existing National Water Quality Assessment (NAWQA) Program water-quality stations located on the Snake River above and below the confluence of the sampled tributaries. The first monitoring site for the NAWQA program was established in the Snake River/Flagg Ranch area in the early 1990's. A second site was established at Moose in 1996. USGS flow monitoring stations are also maintained at other locations in the park, including Pacific Creek, Buffalo Fork, and Spread Creek.

Much surface water quality work has focused on backcountry and high-alpine streams and lakes. For example, testing for fecal coliform, including DNA source tracking of *E.coli*, began in 1996 in selected backcountry streams. Similarly, the trophic state of select alpine and low-elevation lakes was documented between 1995 and 1997. The project found most of the high-elevation lakes to be oligotrophic to slightly mesotrophic, while many low-elevation lakes (e.g., Cygnet Pond, Swan Lake, and Two Ocean Lake) are eutrophic. The Bureau of Reclamation also continuously monitors Jackson Lake levels.

Approximately 23 wells adjacent to sewage ponds and leach fields within park boundaries are presently being monitored and evaluated twice a year, in conjunction with the WYDEQ and the USGS, for basic water quality parameters, fecal coliforms, and nutrients. Additionally, Snake River pit groundwater levels are monitored on a biweekly basis from wells installed by the USGS in 1997.

Snowpack data has been collected in Jackson Hole since the early 1900's, typically to forecast runoff and potential irrigation water supplies. Currently, the snowpack distribution in and around GRTE is being studied because of its relationships to animal movement, the location of winter ranges, and the availability of forage. Correlation between snowpack and soil moisture, forage production, plant phenology, and other plant/soil moisture and animal responses are also considered. The snowpack distribution study in Grand Teton is an NPS-driven project that is being carried out through a cooperative agreement with the NRCS, Montana State University, and Colorado State University. The objective of the study is to process historic data and produce a geographic information system-based model on snowpack distribution across the Snake River drainage above Jackson, including the lower elevations of GRTE, the National Elk Refuge, and the Gros Ventre watershed.

Yellowstone: Yellowstone National Park has an active water-quality monitoring program. Resources monitored include: chloride flux in major rivers, groundwater monitoring for sewage treatment facilities, groundwater monitoring for closed dump sites, and geothermal inventories. In 2002, Yellowstone initiated a water quality program (Koel et al. 2003). To describe and understand spatial and temporal variability among the many water quality parameters (e.g., chloride flux), 12 fixed sites (11 near USGS gauge stations) were located throughout YELL with a sampling frequency established at two-week intervals, allowing for the detection of large-scale habitat changes and biotic responses (Soballe and Fischer 2001). Gauge stations near water quality sites will allow flow-weighted calculations to be estimated for various chemical parameters. In addition, four sites will be established at historic Yellowstone Lake water quality sampling stations (Koel et al. 2002a).

Yellowstone also participates in the NAWQA program and has monitoring stations at Soda Butte Creek at the park boundary, Blacktail Deer Creek, and on the Yellowstone River near Yellowstone Lake outlet. The NPS, USGS, and others have conducted pollution studies on Soda Butte Creek since the 1960's. The USGS also maintains gauging stations at various locations within and near Yellowstone National Park including the Madison River, Gallatin River, Yellowstone River at Yellowstone Lake outlet, Soda Butte Creek, Gardner River, and Yellowstone River at Corwin Springs. More than a dozen additional stations have been operated by the USGS at various times within park boundaries. Backcountry lake surveys were conducted from 1963-1986 (Jones et al. 1986); 112 lakes were surveyed for physical, chemical, and biological parameters. Although no such surveys have been completed since 1987, NPS staff plan to reinitiate this program (Koel et al. 2002a).

Four rivers draining Yellowstone National Park (the Fall, Madison, Snake, and Yellowstone Rivers) have been geothermally monitored for chloride flux, a surrogate for heat flow measurements, from 1983 through the present, with the exception of 1995 and 1996 (Norton and Friedman 1991, Norton and Friedman 1985).

To monitor fish, stream flow, and allocated withdrawals in Reese Creek, a Parshall flume and gauges were installed in 1984. Reese Creek, which is compromised by historical irrigation practices, flows along Yellowstone's northern boundary.

4. GEOLOGIC

Bighorn Canyon: While the geology of the Bighorn Canyon-Hardin area was described by Richards in 1955, few geologic inventory and monitoring efforts, outside of discontinued photo monitoring of Bighorn Caverns and monitoring of slumping at Big Bull Elk Basin, have occurred within BICA boundaries. Parker et al. (1975) extensively surveyed soils within the Montana portion of BICA in 1975. Another soil survey for selected portions of BICA within Bighorn County, Wyoming was initiated in the mid-1990s. The NRCS holds the data that was gathered.

Grand Teton: The NRCS has classified and mapped 44 soil series in GRTE and in JODR (Young 1982).

Yellowstone: Seismicity has been routinely recorded in Yellowstone since 1973. Until 1981, the USGS operated the network (Pitt 1987). Since 1984, the seismic data has been acquired by a digital recording system at the University of Utah Seismograph Stations (Nava and Smith 1996). This permanent network consists of 19 seismometers. Movement of the Yellowstone caldera has been monitored since 1987 with a network of 15 continuous global positioning system (GPS) stations. The Yellowstone GPS network extends 249 mi (400 km) across the area affected by the hypothesized hotspot. A total of 274 stations have been observed in five field campaigns (1987, 1991, 1993, 1995, and 2000) that included cooperative support from the National Geodetic Survey and Massachusetts Institute of Technology. Both seismic and volcano monitoring are currently conducted under the auspices of the Yellowstone Volcano Observatory (YVO), a partnership established in 2001 between the USGS, Yellowstone National Park, and University of Utah (Olliff 2002).

II. CONCEPTUAL ECOLOGICAL MODELS

A. INTRODUCTION AND APPROACH

A conceptual model is a visual or narrative summary that describes the important components of an ecosystem and the interactions among those components (NPS 2003d). These interactions include how agents of change influence the structure or function of natural systems. Conceptual models show the interconnectedness of ecological processes, whether naturally occurring or anthropogenically driven. Conceptual models further help identify how major drivers and stressors will impact ecosystem components (Barber 1994). Most relevant to the Vital Signs Monitoring Program, conceptual models can help identify possible indicators for monitoring long-term ecosystem health.

Conceptual models

- are socially negotiated pictures of the universe that inform the ongoing life of society (Christie 1990);
- formalize our understanding of natural processes—this formalization facilitates cross-discipline, cross-community dialogue between scientists, resource managers, and the general public.

1. WHAT WILL THE NPS MONITORING PROGRAM LEARN FROM CONCEPTUAL MODELING?

Conceptual models provide at least two key benefits to the NPS monitoring program (Plumb 2002):

- understanding ecosystem structure, function, and interconnectedness at varying temporal and/or spatial scales enables identification of vital sign indicators for assessing ecosystem health in parks, and
- understanding the range of natural and human-induced ecosystem variability helps park managers plan adaptive management programs, determine at what threshold variances these programs should be instituted, and then measure the results of the management programs to assess their value.

2. PREPARATION AND SELECTION OF CONCEPTUAL MODELS

Conceptual models for monitoring purposes must demonstrate the strength and direction of linkages between ecosystem components and the value being monitored (Olsen et al. 1992), plus show the anticipated system response to stressor inputs (USDA 1999). To accomplish these goals, the GRYN team considered employing each of the three types of conceptual models typically in use:

- Narrative conceptual models portray an ecosystem through word description, mathematical or representational formula, or a combination of both.
- Tabular conceptual models generally describe an ecosystem by presenting a two-dimensional array of related ecosystem components in the familiar row-and-column format.
- Schematic conceptual models take three forms: (1) *Picture* models that depict ecosystem function, varying from simple XY plots to complicated diagrams and drawings; (2) *Box-and-arrow* models that provide reduced form ecosystem representations focusing on key ecosystem components and the relationships among them; and (3) *Input/output matrix* models are a subset of box-and-arrow

models that explicitly indicate mass and/or energy flow between ecosystem components.

Based on rigorous literature review, Plumb (2002) developed a list of 35 desirable vital sign characteristics, broken into four categories: (1) conceptual relevance, (2) feasibility of implementation, (3) response variability, and (4) interpretation and utility. Next Plumb rated the ability of seven model types (narrative, tabular, and five subtypes of schematic models) for their ability to provide meaningful information with respect to the 35 desirable vital sign characteristics (that list includes those identified by NPS, as shown in Table II.1). Each model type showed inherent strengths and weaknesses, in part because observation scale affects measurements and inferences from biological systems (USDA 1999). Picture models, for example, are excellent for representing sweeping concepts but often poor at providing sufficient detail for selecting vital signs.

Table II.1: Desirable indicator characteristics (NPS 2003d)

- ❖ have dynamics that parallel those of the ecosystem or component of interest,
- ❖ are sensitive enough to provide an early warning of change,
- ❖ have low natural variability,
- ❖ provide continuous assessment over a wide range of stress,
- ❖ have dynamics that are easily attributed to either natural cycles or anthropogenic stressors,
- ❖ are distributed over a wide geographical area and/or are very numerous,
- ❖ are harvested, endemic, alien, species of special interest, or have protected status,
- ❖ can be accurately and precisely estimated,
- ❖ have costs of measurement that are not prohibitive,
- ❖ have monitoring results that can be interpreted and explained
- ❖ can be measured with little or no environmental impact, and
- ❖ have measurable results that are repeatable with different personnel.

Based on this matrix comparison, the team decided to emphasize hierarchical box-and-arrow models for its conceptual modeling work for the following reasons:

- since ecosystem structure and function operate at multiple temporal and spatial scales, the most useful conceptual models are hierarchical in structure, meaning that large-scale constraints (e.g., climate) are shown to cascade down to small-scale measurable endpoints (e.g., soil moisture) (Allen and Hoekstra 1992; Allen and Starr 1982); and
- box-and-arrow models can be simple, easy to follow, and highly intuitive.

B. CONCEPTUAL MODELING METHODS

In January 2002, the Program Manager convened a meeting of five ecologists—from regional academic institutions and the NPS—who are highly familiar with the GRYN parks. That meeting, and follow-up work by a team consisting of these ecologists and Network staff, answered two non-trivial questions: what do we model and how do we model it?

1. WHAT DO WE MODEL?

The team considered numerous methods for dividing the Network into logical, ecologically significant units for conceptual modeling. This difficult process proved even more challenging because of the great diversity in climate, geology, landscape, aquatic resources, and biota brought on by the addition of Bighorn Canyon to the more similar parks of the Greater Yellowstone Ecosystem.

As shown in Figure II.1, the team took a structured approach to dividing the Network into ecological subunits. To accommodate all possible ecosystems, the team first selected two intuitive levels of ecological organization—terrestrial and aquatic—and then added a third, geothermal, because of the unique thermal features found in Yellowstone (and, to a small extent, Grand Teton). An atmospheric break out was considered, but it was omitted after recognition that atmospheric components and/or climate would be drivers in conceptual models for each of the other ecosystem types.

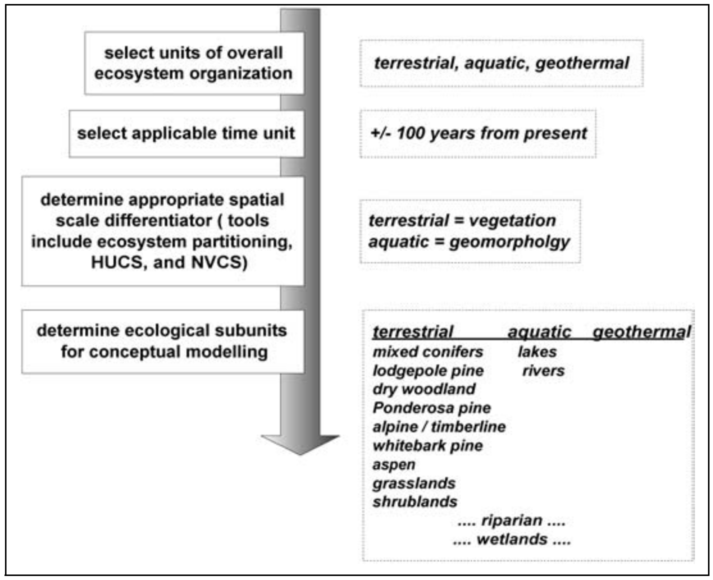


Figure II.1: Process steps for determining conceptual models required to adequately cover all levels of ecosystem organization. GRYN results shown to the right.

Next the team considered temporal and spatial modeling constraints to further define the ecosystems to be modeled. A time frame of one century before and after present was chosen as the desired scale of applicability of the models. This time frame encompasses the majority of reliable historic data and knowledge developed for the ecosystems, plus the period of immediate utility for the vital signs eventually selected.

To find the proper spatial scale and system for conceptual modeling, the team evaluated three widely accepted methods:

- Ecoregion classification (Bailey 1995; Omernick 1987) yielded spatial scales that were too large for finding fine detail in ecosystem monitoring.
- Hydrologic Unit break outs at fourth-level watersheds (i.e., HUC4), with some aggregation, resulted in excellent spatial resolution, subdividing the network into readily identifiable, reasonably scaled basins that had the benefit of closely aligning with existing land management boundaries.
- National Vegetation Classification Standards (NVCS) (Federal Geographic Data Committee 1997). This physiognomic classification closely parallels terrestrial vegetation ecosystems described in existing classifications or classifications under development.

While differentiation by HUC appeared reasonable, dominant vegetation type provided a more logical framework on which to build the terrestrial conceptual modeling efforts. Dominant vegetation is influenced by, and influences, terrestrial ecosystems, and thus provides a logical link to the major ecosystem to be modeled. This influence can be seen in vegetation change across terrestrial environmental gradients (e.g., elevation and soil types). Similarly, ecosystem stressors vary by dominant vegetation; forests, for example, are susceptible to mountain pine beetle and blister rust, while grasslands are susceptible to insect defoliation and herbivory.

Numerous terrestrial vegetation classes were proposed, leading to an unwieldy number of possible conceptual models. A lumping process followed (for example, gathering proposed Engelmann spruce, Douglas-fir, and alpine fir models into a single "mixed conifers" model). Nine terrestrial ecosystem types, as expressed by dominant vegetation, resulted.

The team combined the nine terrestrial types with two aquatic systems (lake and river), two aquatic/terrestrial systems (wetlands and riparian), and a geothermal type to cover the full range of environments found in the GRYN. Figure II.1 shows the 14 conceptual models resulting from the selection process described. Development of these models was assigned to Network ecosystem experts—several who were involved in the model selection process—as shown in Table II.2.

Table II.2 GRYN conceptual models and model authors.

Model Author	Affiliation	Model(s) Created
Dr. Duncan Patten	Big Sky Institute, Montana State University	Riparian, Wetlands, Alpine/Timberline, Aspen (shared)
Dr. Glenn Plumb	Yellowstone National Park	Grasslands, Shrublands
Dr. Bob Hall	Dept of Zoology, University of Wyoming	Lakes, Rivers
Dr. Dan Tinker	Dept of Botany, University of Wyoming	Lodgepole Pine, Ponderosa Pine, Whitebark Pine, Mixed Conifers, Aspen (shared)
Drs. Cheryl Jaworowski and Henry Heasler	Yellowstone National Park	Geothermal
Cathie Jean	Greater Yellowstone Network	Dry Woodland

2. <u>How do we model it?</u>

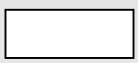
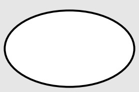
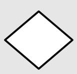
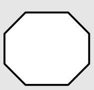
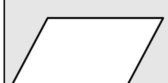
To provide uniformity in the conceptual models, the team developed a process and format for model creation. Each of the 14 conceptual models was based on review of the scientific literature, focused on determining:

- specific resources that are vulnerable to natural and anthropogenic disturbances;
- primary drivers and stressors on ecosystem integrity, assumptions being made about these drivers and stressors, and assumptions about, or predictions of, ecosystem response to the drivers and stressors;
- specific actions that should be taken to understand the status of ecosystem integrity; and
- concerns and questions that can be addressed fully or in part with short- and long-term monitoring data.

Based on the literature review, model authors created narrative conceptual models that included (1) an overview of the ecosystem, (2) a description of system drivers, (3) a description of stressors and ecological responses, and (4) a list of literature cited. Additionally, the model authors created hierarchical box-and-arrow conceptual models for each ecosystem (in some cases, submodels were also created). Those box-and-arrow models contained five components: drivers, stressors, ecological effects, indicators, and measurements (definitions for these components can be found in Table II.3). Finally, the model authors developed lists of potential indicators—including a justification of the listing and the resource to be monitored—revealed by the conceptual models.

Figure II.2 provides an example of one of the 14 hierarchical box-and-arrow conceptual models created for the Network (the suite of 14 narrative and box-and-arrow conceptual models derived for the GRYN are presented in full in Appendix VI). This model shows forcing functions that operate at large scales (i.e., drivers) on riparian ecosystems include geology and hydrogeomorphology, climate, biology, and humans. Ecosystem stressors, such as wet and dry cycles, ungulate grazing, beaver, and recreation act more directly to cause riparian system change. The riparian zone responds (ecological effects) to these drivers and stressors through changes in fluvial, vegetation, and herbivore dynamics. Thus channel morphology and the riparian vegetation community act as indicators of riparian

Table II.3: Definitions of conceptual model components.

Symbol	Model component
n/a	**Monitoring attributes** are any living or non-living feature or process of the environment that can be measured or estimated and that provide insights into the state of the ecosystem.
	**Drivers** are major, naturally occurring, forces of change such as climate, fire cycles, biological invasions, hydrologic cycles, and natural disturbance events (e.g., droughts, floods, lightening-caused fires) that have large-scale influences on the attributes of natural systems. Drivers can be natural forces or anthropogenic. Drivers operate on national or regional levels.
	**Stressors** are physical, chemical, or biological perturbations to a system that are either (a) foreign to that system or (b) natural to the system but applied at an excessive [or deficient] level (Barrett et al. 1976). Stressors cause significant changes in the ecological components, patterns and processes in natural systems. Examples include air pollution, water pollution, water withdrawal, pesticide use, timber harvesting, traffic emissions, stream acidification, trampling, poaching, and land-use change. They act together with drivers on ecosystem attributes. Stressors operate on more localized levels than drivers.
	**Ecological effects** are the physical, chemical, biological, or functional responses of ecosystem attributes to drivers and stressors.
	**Indicators** are an information-rich subset of attributes with respect to providing insight into the quality, health, or integrity of the larger ecological system to which they belong (Noon 2002). **Vital Signs** describe all the elements, processes, and indices actually measured or evaluated. Thus, all indicators selected for evaluation are Vital Signs, but all Vital Signs may not be indicators.
	**Measurements** are the specific variables used to quantify the condition or state of an attribute or indicator. These are specified in definitive sampling protocols. For example, stream acidity may be the indicator, while pH units are the measure.

zone health. These indicators can, in turn, be represented by quantifiable measures such as (1) presence and/or abundance of benthic or riparian species, and (2) river channel depth and width, either or both of which could be used as part of a monitoring program.

The riparian model shows that hierarchical, box-and-arrow models provide an abstraction of ecosystem components and dynamics, leading to potential indicators of ecosystem health. And Figure II.2 illustrates another important facet of conceptual modeling: while candidate vital signs generally appear as indicators or measurements in the model, vital signs can emerge from any level in the model. Stressors sometimes have preferable indicator characteristics (described more completely in Chapter III) to the indicators revealed via the model hierarchy. In the riparian model, for example, the model author recognized exotic plants as an excellent indicator, in this instance a measurement (through riparian vegetation

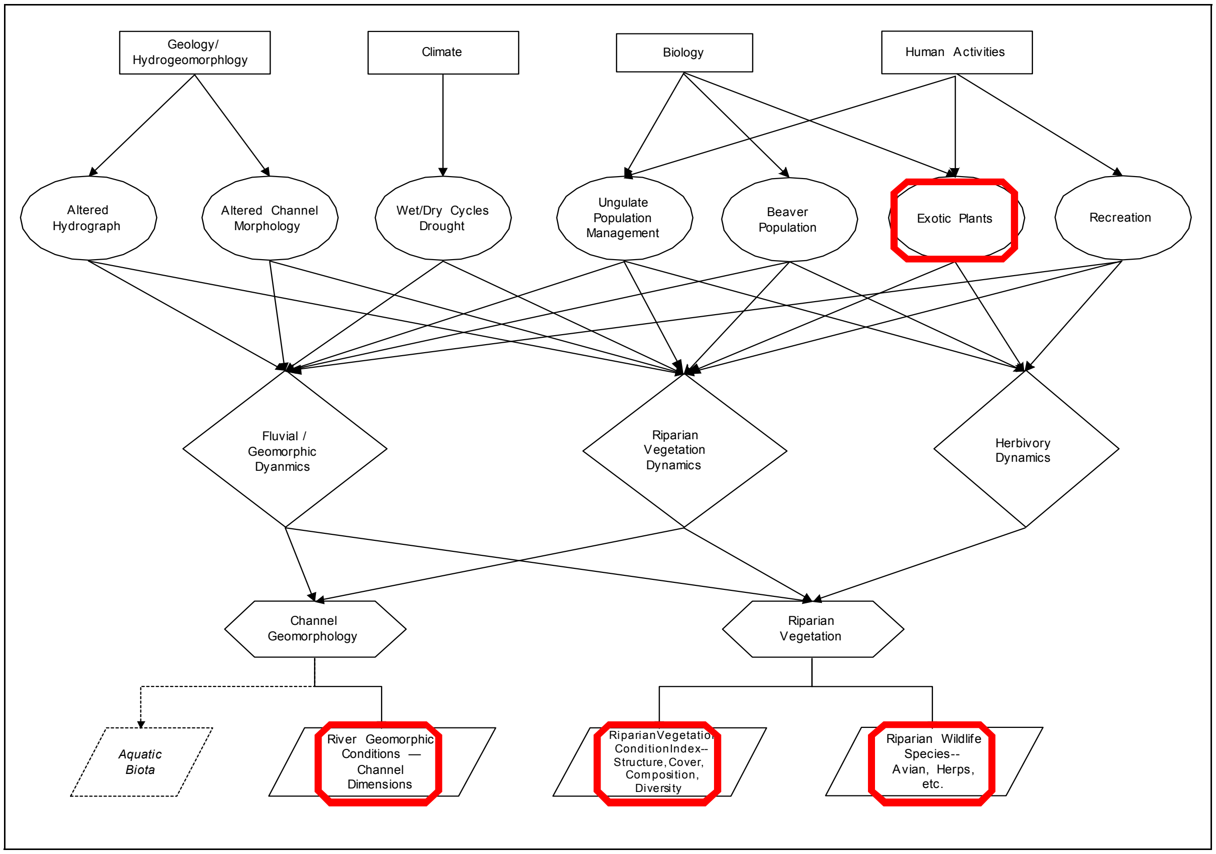


Figure II.2: Riparian ecosystem model for the Greater Yellowstone Network. Candidate vital signs revealed via conceptual modeling are shown boxed in red. See Table II.3 for definitions of hierarchical model components.

indices) that also acts as a stressor.

Along with box-and-arrow models, the conceptual modeling team was encouraged by the Program Manager to employ tabular models where appropriate. Table II.4 shows one example of such a model, focusing on environmental threats to riverine systems, broken out by HUC subunits across the GRYN.

3. Summary of GRYN Ecosystem Drivers and Stressors

Drivers and stressors, whether naturally occurring or human-induced, act as forcing functions on a system. In the following section, we discuss the drivers and stressors described in the 14 conceptual models created for the GRYN.

Drivers

Drivers include such forcing mechanisms as climate, biological invasions, droughts, floods, and fires. Drivers operate on both regional and landscape levels. While often of natural origin, drivers can also include human impacts (e.g., fire and herbivory management).

Table II.5 shows the suite of drivers described in the 14 narrative and conceptual models found in Appendix VI. The ecosystems modeled are shown as column headings, with drivers shown as row headings. For convenience, ecosystem drivers are organized into four

Table II.4: Riverine/riparian ecosystems--environmental threats for each ecosystem type by HUC unit.

National Park	HUC Units	Gravel bar/ edge wetlands	Herbaceous meadow	Willow/shrub	Cottonwood	Cottonwood/ willow/shrub	Conifer/ willow/shrub	Lake shore	Riparian exotics (dominant)
GRTE	Jackson Lake	1,2,3,4,5,6	3,4,5,6	1,2,3,4,5,6	1,2,3,4,5,6	1,2,3,4,5,6		1,4,5,6	
	Moran			3,4,5,6		??	3,4,5	1,4,5	
	Jenny Lake	3,4,5,6		3,4,5,6		3,4,5,6	3,4,5	4,5,6	
	Spread Creek	1,2,3,4,5,6	3,4,5,6	1,2,3,4,5,6	1,2,3,4,5,6	1,2,3,4,5,6	3,4,5		
	Fall Creek	3,4,5		3,4,5		??	3,4,5	4,5,6	
BICA	Black Canyon	1,2,4,5,6		1,2,4,5,6				1,2,4,5,6	
	Layout	1,2,4,5,6			1,2,4,5	3,4,5		1,2,4,5,6	
	Fire Springs	1,2,3,4,5,6		1,2,3,4,5,6	1,2,4,5,6	1,2,3,4,5,6		1,2,4,5,6	1,2,3,4,5,6
YELL	Gallatin	4,5,6	5,6	3,5			3,5		
	Northern Range	4,5,6	3,4,5,6	3,5,6	3,5,6	3,5,6	3,5,6	3,5	
	Madison	4,5,6	3,4,5,6	3,5,6	?	?	3,5,6	3,5	
	Yellowstone	4,5,6	3,4,5,6	3,5,6			3,5,6	3,4,5,6	
	Henry's	4,5,6	3,4,5	3,4,5			3,5,6	3,5	
	Snake	4,5,6	5,6	3,5,6			3,5,6	3,4,5,6	

Environmental threats (stressors)

1	**Altered hydrology**
2	**Altered channel**
3	**Herbivory**
4	**Invasive species**
5	**Climate change/Drought**
6	**Recreation**

Table II.5: Ecosystem drivers as presented by the 14 ecosystem conceptual models.

		Terrestrial											Aquatic		Geo-logic
		Alpine/Timberline	Whitebark Pine	Mixed Conifers	Lodgepole	Aspen	Ponderosa Pine	Dry Woodland	Shrublands	Grasslands	Wetland	Riparian	Lakes	Rivers	Geothermal
Atmospheric	Climate	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	Atmospheric deposition												X	X	
Terrestrial	Humans	X				X		X	X	X	X	X	X	X	
	Fire	X	X	X	X	X	X								
	Exotic/Invasive Species	X		X							X	X	X	X	
	Insects and disease	X	X	X	X		X								
	Herbivory	X			X	X	X								
	Clark's Nutcracker		X												
Aquatic	Morphometry												X		
Geologic	Parent material/soils	X		X	X	X		X	X	X	X		X	X	
	Hydrogeomorphology										X	X			
	Elevation/Topography			X	X										
	Magma chamber/geothermal activity									X					X

categories: atmospheric, terrestrial, aquatic, and geologic.

Atmospheric drivers: Not surprisingly, ***climate*** operates as a driver on all 14-ecosystem subunits modeled, across all parks in the Network. Weather patterns, in particular the magnitude and timing of temperature changes and precipitation inputs, have a major influence on all ecosystems (Despain 1990).

The climate of Yellowstone and Grand Teton is characterized by long, cold winters and cool, dry summers, which heavily influence the abundance and location of vegetation communities. Alpine and timberline communities, which provide the extreme example, are strongly limited by wide temperature fluctuations (Tranquillini 1979). High radiation levels at high elevations can cause the ground surface to heat during the day followed by rapid nighttime cooling. Extreme cold temperatures dictate physiological processes and are considered one of the primary causes of timberline; that is, only plants with metabolic systems that can function at very cold temperatures during the short alpine growing season can grow at these elevations. Temperature extremes may function synergistically with other natural stressors to create even more extreme conditions. For example, wind combined with low temperatures may limit forest growth, particularly at high elevation.

Most of the precipitation in Yellowstone and Grand Teton falls in the form of snow. Winter snowpack melts rapidly in May and June, providing much of the water available for vegetation growth, wetland sustainability, and hydrothermal feature recharge. In addition, periods of seasonal drought, such as were experienced during the summer of 1988, may exert considerable influence on soil and fuel moisture, as well as fire regimes. Drought exerts strong influences on all Network ecosystem subunits, from species richness in wetlands to primary production in grasslands and aspen communities, to stream flow and oxygen carrying capacity in riverine systems.

The climate of BICA is often described as temperate and semiarid. While snow and ice may play the predominant role in Yellowstone and Grand Teton, storm events appear to be the major hydrologic driver for river systems, springs, and riparian zones in BICA. Snowmelt in the headwater parks creates a reliable hydrographic peak while erratic storms (and controlled mainstem flows) produce uncertain hydrographs in BICA. Recruitment of many riparian species is triggered by, or coincides with, the spring snowmelt peak that occurs in May and June (Scott et al. 1993). However, because of controlled flows, the peak may extend beyond seed dispersal, interfering with the normal cottonwood recruitment process.

Precipitation, which is quite variable across BICA, drives vegetation communities. BICA's northern end receives over 19 inches (48 cm) of precipitation per year; approximately two-thirds of this falls during spring and early summer, and the rest as snow (Knight et al. 1987). Due to this critical summer precipitation, ponderosa pines are limited to the more northern end of BICA. The drier southern end of BICA receives, on average, only slightly more than seven inches (18 cm) of precipitation per year (Knight et al. 1987) and thus supports a dry woodland ecosystem. The climate is relatively cooler and moister at higher elevations, where mixed conifer forests occur.

Atmospheric deposition acts as a large-scale driver in all three parks. Nitrogenous compound deposition, resulting from fossil fuel combustion (summer or winter traffic, within the parks or from nearby urban centers), can result in acidification of fragile alpine lakes having low acid-neutralizing capacity. Additionally, riverine systems can receive large nitrogen pulses at snowmelt, leading to eutrophication. BICA has the potential for sulphate fallout from the nearby Colstrip coal-fired power plants.

Terrestrial drivers: Humans, fire, and exotic species are prevalent drivers affecting many of the modeled ecosystem subunits across all three Network parks. Insects and disease, herbivory, and the Clark's Nutcracker also act as important, though less ubiquitous, ecosystem drivers.

Human impacts were found to be significant drivers in many ecosystems. Human disturbance of aquatic and riparian systems is common to all three Network parks and includes acid deposition, nutrient loading, pollution, altered hydrology (e.g., dams, rip rap), and manipulated biotic assemblages (e.g., introduced game fish species, loss of riparian forests). Humans also strongly influence terrestrial systems through fire and grazing management practices, and recreational activities.

Fire, both managed and natural, whether present or absent, is an important driver across all three parks and across numerous terrestrial systems occurring at different elevations. fire suppression (in combination with drought and grazing), for example, favors an increase in juniper cover and invasion into new sites in BICA. Suppression of fires in ponderosa pine forest has, similarly, resulted in lower seedling mortality and subsequent dense, doghair stands. Fire suppression can accelerate the succession of grassland or shrublands to woodlands in two ways: (1) directly by preventing mortality in young, more easily burned stands, and (2) indirectly by favoring the development of shrublands that serve as nurse plants for seedling survival (Wright et al 1979).

Whitebark pine relies on fire for its resiliency. Historically, whitebark pine burned every 50-300 years. Under current fire suppression practices, however, it has been estimated that whitebark pine forests will burn at 3,000-year intervals (Kendall n/a). This drastic change in the periodicity of fire makes seral whitebark pine trees vulnerable to disease and insects, and hence more likely to be out competed by shade-tolerant conifers.

In lodgepole and mixed conifer ecosystems, large, intense fires may help control episodic outbreaks of mountain pine beetle by burning entire stands where significant outbreaks have occurred. Additionally, fire or lack thereof, has important cascading effects into critical processes such as coarse woody debris accumulation, changes in plant species composition, and net primary productivity.

Exotic species have the potential to out-compete and displace native species and thereby disrupt entire ecosystems. In BICA, for example, tamarisk and Russian olive, have displaced native species in many riparian areas. In Yellowstone, whirling disease and illegally introduced lake trout threaten native cutthroat populations, and thus threaten to collapse a food chain that culminates in grizzly bears and bald eagles. In forest, wetland, and riparian ecosystems, invasion by exotic plant species may inhibit the germination and establishment of replacement trees, shrubs, and forbs, causing a shift in plant community composition and resultant cascading effects.

Invasive species often take over sections of ecosystems, choking out native species and consuming valuable resources. Many times, these invasive species are not palatable to native ungulates, thus decreasing available forage. In addition, the possibility exists for invasive plants to pass diseases to native species or hybridize with natives, causing loss of genetic integrity. By monitoring the species richness and distribution of invasive plant species, the status and trends of these populations, as well as the effectiveness of current management techniques and possible preventative actions, can be determined.

Insects and disease, a natural, often cyclical occurrence in many ecosystems, can dramatically shape forest ecosystem structure and function. Bark beetle and budworm can alter timberline forests. Epidemic outbreaks of blister rust have accelerated the successional process in many whitebark pine forests (Keane 2001), and outbreaks of native mountain pine beetles, such as occurred during the 1970's in Yellowstone, result in the death of many trees (Brown 1975, Baker and Veblen 1990, Despain 1990). Pine beetle outbreaks may occur during years of inadequate precipitation, when mature trees are unable to produce sufficient resins to defend against beetle infestation (Knight 1994). Plant parasites, such as dwarf mistletoe and comandra blister rust, are common in these mixed conifer and lodgepole pine forests. Mistletoe may reduce tree growth or even result in tree death, and has been labeled the most important problem in lodgepole pine forests (Knight 1994). Pine beetles or other plant pathogens can also kill ponderosa pine.

Tree mortality, regardless of forest type, can lead to changes in runoff and erosion, canopy openings that allow the establishment of new species (Keane et al. 1994; Arno 1986), changes in coarse woody debris biomass, increases in understory vegetation production (Knight 1994), and changes in fuel availability and fire susceptibility.

Herbivory, both by insects and ungulates, may reduce plant cover and/or kill young seedlings and saplings (Houston 1982, Singer et al. 1989). Wildlife or livestock grazing may drive plant community changes by selective removal of native species. New species moving into these disturbed landscapes may be natural (though not before prevalent) or exotic. Herbivory may drive large-scale changes in landscape patterns; for example it may modify the spatial extent and abundance of aspen stands in Yellowstone. Some species, such as elk, deer and antelope, affect all Network parks, while others affect specific park units, such as wild horses in BICA and bison in GRTE and YELL.

Clark's Nutcrackers are almost exclusively responsible for the dispersal of whitebark pine seeds (Hutchins and Lanner 1982) and hence the major driver for the Yellowstone and Grand Teton ecosystems, and for limber pine in Bighorn Canyon. The birds cache multiple seeds together in open areas, often in recently burned forests, and unclaimed caches germinate and grow in the absence of shade and competition (Tomback et al. 1990). This form of avian dispersal of seeds often results in the germination and establishment of multi-stemmed trees (Furnier et al. 1987). The relatively large seeds serve as an important food source for at least 110 species of animals, including grizzly bears and red squirrels (Tomback 1989).

Aquatic drivers: ***Morphometry*** serves as the only aquatic driver for Network parks, with large-scale limnological effects. Exogenous processes (glacial scour, plate movement, dams, differential cooling of lava [in the case of Yellowstone Lake]) form lakes and determine their morphometry. Morphometry, in turn, determines most aspects of lake function, including such critical ecosystem attributes as temperature stratification, turnover timing, date of "ice out", primary plant production, littoral zone development, and spawning habitat.

Geologic drivers: Parent materials and soils drive numerous ecosystem subunits across all three Network parks. Hydrogeomorphology, elevation and topography, and the magma chamber are also important geologic drivers.

Parent material and soil type help determine soil moisture content, which strongly influences plant community recruitment, composition, and abundance. Wetland plants, for example, are limited to areas of inundation and hydric soils. Soil nutrient and organic matter content drives root mass extent, which strongly affects soil stability and erosional processes. Parent material strongly influences groundwater hydrology, helping determine the existence and location of seeps and springs, critical resources in all three Network parks, and especially BICA. River and lake morphometry, as well as nutrient characteristics, are also largely determined by the associated geologic substrate.

The parent materials for soils across much of the Greater Yellowstone Ecosystem are volcanic in origin. Two different parent materials—rhyolitic and andesitic soils—derived from underlying bedrock, determine the soil characteristics in Yellowstone. Differences in these parent materials determine soil texture, water holding capacity, and nutrient supply and availability. Rhyolitic soils are sandier, while andesitic soils contain much more clay (Despain 1990). Calcium is ten times more abundant in soils derived from andesite (Despain 1990).

In BICA, mixed conifer and dry woodland forests on East Pryor Mountain occur primarily on shallow soils, where fractured bedrock reservoirs may serve as water sources during an otherwise dry growing season (Knight et al. 1987).

Hydrogeomorphology–the interplay between aquatic systems (i.e., precipitation, surface water, and groundwater) and the makeup and relief of the land—strongly influences riparian and wetland ecosystems. Patterns of riparian communities along elevation gradients and geomorphic gradients are similar throughout most of the GRYN. Structural similarities of riparian communities occur across the GRYN because they are related to successional dynamics, which are driven by common fluvial-geomorphic processes. For example, point-bars, channel margins, and island deposits provide exposed sediment that supports young riparian plants along meandering and braided rivers throughout the region.

The GRYN parks have heterogeneous landscapes ranging from mountains to broad valleys and deep canyons. Consequently, streams flowing from the mountains transect a diverse geomorphology that creates steep gradients through narrow, shallow-bedrock valleys as well as low-gradient, broad valleys with deep alluvium. Throughout this region, variability in valley morphology directly influences the extent and type of riparian communities and wetlands (Patten 1998). Streams flowing through broad valleys with low gradients may be lined by woody and/or herbaceous riparian vegetation. If the water table is shallow, wetland herbaceous plants (e.g., sedges and wetland grasses) may extend for some distance from the river creating fens in some areas. These wetland areas often are devoid of woody species because the herbaceous cover may prevent establishment of willows, cottonwoods, or other woody plants.

Geomorphic influences in the GRYN may affect how successful recruitment is for riparian species. Many riparian species require bare moist soil for recruitment (Stromberg et al. 1991; Scott et al. 1996). Many rivers of the north Rockies have gravel- or cobble-lined channels; however, fine sediment in these rivers may be held in overbank ice in winter and deposited in spring where riparian recruitment may occur. Flash floods, particularly in BICA, are large redistributors of sediment and nutrients. Finally, river geomorphology, and consequently riparian and wetlands extent, is often controlled or altered by beaver activity (Naiman et al. 1986). Relatively permanent beaver dam structures collect sediment, altering sediment delivery downstream, and elevate local groundwater, enhancing growth and survival of most riparian species (Johnston and Naiman 1987). Eventual abandonment of beaver dam sites results in floodplains covered in fine sediments and a successional process that reverts the vegetation back to that occurring prior to beaver arrival.

Elevation and topography drive lodgepole and mixed conifer ecosystems, in part due to their effect on soils. In Yellowstone, for example, andesitic soils are relatively more fertile and often occur at higher elevations, while rhyolitic soils are found most often on drier sites, and are typically nutrient limited (Despain 1990). Elevation and topography (e.g., aspect) also shape forest growth through such factors as temperature profiles, wind and sun exposure, and moisture availability.

The ***magma chamber and geothermal activity*** are the ultimate geophysical drivers in Yellowstone. Geothermal fluids convect towards the surface via fracture systems that are self-sealing and tectonically sensitive. Geothermal fluids from deep, intermediate, and shallow depths mix and interact with meteoric waters. These waters eventually discharge as hydrothermal features in the geyser basins of Yellowstone, with subsequent cascading effects on terrestrial and aquatic plant and animal life via thermal and geochemical modifications to landscapes, airsheds, and waterways.

Stressors

Stressors, like drivers, act as forcing functions on ecosystems. Stressors are differentiated from drivers because they generally operate at local, rather than regional (or larger), scales. Stressors are physical, chemical, or biological perturbations to a system that are either (a) foreign to that system or (b) natural to the system but applied at an excessive, or deficient, level (Barrett et al. 1976). Stressors cause significant changes in the ecological components, patterns, and processes in natural systems. Examples of stressors include air pollution, water pollution, water withdrawal, pesticide use, timber harvesting, traffic emissions, stream acidification, trampling, poaching, and land-use change.

Review of the important stressors mentioned in the ecosystem conceptual models reveals several characteristics that are relevant to creating a scientifically credible monitoring strategy:

- Ecosystem drivers, acting on regional scales, can also act more locally as stressors. Examples include herbivory, human impacts, and fire.
- Numerous stressors act on many of the ecosystem subunits modeled. These stressors tend to have cascading effects that propagate disturbance and change beyond their immediate zone of influence, or operate across multiple trophic levels or at multiple spatial and temporal scales. Examples of these types of stressors include exotic species, insects, disease, temperature and precipitation cycles, and fire.
- Other stressors are strongly associated with specific ecosystem submodels; for example, carbon dioxide concentration and levels of UV radiation are only classified as prominent forcing functions for alpine/timberline ecosystems.
- Energy dynamics play a major role in many ecosystems stressors. Nutrient availability and input across aquatic and terrestrial ecosystems are major agents of change, as are physical processes such as erosion, wind, and ice abrasion.
- Mass flow dynamics also play a major role in many ecosystem stressors. Examples of mass flow dynamics include sediment movement, erosion, earthquakes, and volcanism.
- At localized levels, man continues to be a major agent of change in the parks of the GRYN. Human impacts to aquatic and terrestrial ecosystems can be seen in such areas as ungulate management, atmospheric nutrient inputs, altered hydrology, recreation, oil and gas exploration, and geothermal vandalism.

Understanding the range of stressor variability—whether short- or long-term, natural or human-induced—plays a critical role in assessing current and future ecosystem health. For example, primary productivity of alpine ecosystems is known to vary with carbon dioxide partial pressure. To understand if and how this stressor is modifying the ecosystem, we must understand if today's rising CO2 concentrations fall within long-term, natural perturbation levels. If not, can we predict how the alpine ecosystem will react? Can management practices be designed and implemented to minimize ecosystem damage? Understanding short-term variability is also critical to assessing ecosystem health. Eutrophying inputs of nitrogenous compounds, for example, are manifested during the short period of snowmelt. Thus, improperly designed sampling regimes might miss the nitrogen pulse.

Because of the similarity of many of the GRYN stressors to the already described drivers, an independent explanation of each stressor is not included. Instead, short discussion of several related stressors that are largely unique from GRYN drivers is provided, as follows.

Water flow, level, temperature, and chemistry: In the semiarid climate that characterizes much of the Network, water availability largely controls the floral and faunal makeup of every ecosystem. Stream flow, plus stream, lake, and reservoir level provide the most ready measures of water availability. Stream flow, the unit volume of water passing a given point on a stream or river over a given time, affects a large array of critical ecological functions, including erosion, sediment and nutrient transport and distribution, native fish spawning success, groundwater recharge, and wetlands vitality. Water level in streams and rivers can be used to directly calculate water flow for channels of known cross section and flow characteristics. In lakes and reservoirs, water level affects littoral zone development and extent, makeup of the benthos, waterfowl utilization, and temperature gradations (and, hence, use by pelagic fish and zooplankton, and periodicity of turnover). For hydrologically managed reservoirs such as Jackson Lake and Bighorn Lake, water levels can swing erratically and unnaturally due to demands such as irrigation or inflow retention during times that would normally bring spring or early summer floods. These erratic swings can remove the link between lakes and their shoreline. For example, soils may go from inundated to dry over short periods, making challenging conditions for littoral or near-shore vegetation development, with a concurrent decrease in allochthonous inputs and disruption in food web dynamics (Hall 2003). Thus, along with water level, *the stability of the water level* can be a critical stressor for reservoirs.

Water temperature varies seasonally, and is often tightly linked to stream flow and water level. Water temperature affects the health and variety of fisheries, the viability of unwanted exotics such as whirling disease, the growth of aquatic plants, the availability of oxygen, and the rate of benthic decay. Upward excursions in water temperature can hasten eutrophication processes brought on by water chemistry changes such as nitrate inputs. Water chemistry, a subset of water quality, reveals chemical environmental stress from sewage outfall, land-use (e.g., agriculture, mining, oil and gas development), power plant or fossil fuel atmospheric fallout (e.g., high lake acidification, nitrates), geologic substrate composition, lack of riparian buffering, and changing geothermal patterns (e.g., changes in chloride flux).

Beaver population is a significant driver for aspen, wetland, and riparian ecosystems in the GRYN. Beaver dams modify streams and rivers by creating ponds and wetlands, thereby elevating water tables and inundating soils. These dramatic changes are reflected through increases in ecosystem diversity. Beaver activity results in more ecological niches and, hence, increases in vegetation and wildlife biodiversity. Presence or absence of beaver directly affects the assemblage of trees (e.g., the survival of aspen seedlings sprouts in areas of elevated groundwater) and forbs present in valley bottoms. Over-population of beavers may cause local alteration of riparian vegetation through excessive harvest of riparian woody plants. Absence of beaver may result in water table declines and associated long-term alteration or loss of riparian vegetation. These effects, in turn, strongly affect the local presence of ungulates, songbirds, amphibians, fish, and insects.

Beaver abundance tends to be cyclical, responding to predators, competitors for woody plants and, in some cases, human influence. Several areas of the GRYN (for example, streams in the Northern Range of YELL) historically supported extensive beaver populations, but these populations have declined or become absent in recent years (Bailey 1930; Wright and Thompson 1935; Jonas 1955). Some of those areas appear to be experiencing a resurgence of beaver and subsequent stressor effects can be expected.

Wind, snow and ice abrasion, windstorms, and blowdowns are regular forces in the GRYN. Wind effects generally increase in prevalence as elevation increases. Wind can break down the protective heat transfer boundary layers formed on physical and biological surfaces, thus resulting in greater cold temperature stress. Consequently, low temperatures become more "penetrating" and potential for freezing increases. Similarly, wind can break down mass transfer boundary layers, thus accelerating desiccation.

Wind may bring warmer temperatures from lower elevations to alpine regions, or sweep cold air masses into the valleys. Wind also drives ice and snow, both of which scour and abrade surfaces and plant tissues. Wind also causes snow to accumulate, thereby stopping photosynthetic processes in localized regions.

Wind can serve as a vector for nutrient redistribution, via soil erosion from exposed surfaces, and blowdown of isolated trees or, in some instances, entire forests (e.g., the 6,000-ha [14,800 acre] event that occurred in the Teton Wilderness in 1987). Blowdown directly affects forest and landscape structure through widespread tree mortality, and the creation and accumulation of coarse woody debris and standing dead trees. Large areas of uprooted trees may also allow for the invasion of new plant species, and may affect the growth rates of the new and existing species.

Finally, wind is the major agent of change for determining the direction and magnitude of grass and forest fires.

Earthquakes and volcanism have the potential to significantly modify ecosystem structure and function, and impact human safety. Several past and contemporary examples from the Greater Yellowstone Ecosystem exist.

In 1959, the largest earthquake in recorded Montana history occurred just outside the west entrance to Yellowstone National Park, killing 28 people and causing over ten million dollars in damage to roads, bridges, and homes. The earthquake was felt as far away as Seattle and caused the partial evacuation of Ennis, Montana, 50 miles (80 km) downstream, for fear of structural damage to the dam at Hebgen Lake[5]. The evacuation was halted when officials realized that the earthquake's most spectacular and lasting effect, a huge landside in the Madison River canyon downstream from Hebgen Lake, had dammed the valley, providing protection from flood. The size of the slide has been estimated at 28 to 33 million cubic meters (37 to 43 million cubic yards) of rock and dirt[6]. Within a few weeks, Quake Lake had formed and today is up to 174 ft (53 m) deep. Other tangible changes from the earthquake included new fault marks up to 20 ft (6 m) near Hebgen Lake and a drop in the bedrock beneath the lake that caused a seiche (surface oscillation in the lake). Subsidence was remarkable: maximum subsidence was 22 ft (6.7) m in Hebgen Lake Basin; roughly 50 mi^2 (130 km^2) subsided more than 10 ft (3 m); and about 193 mi^2 (500 km^2) subsided more than 1 ft (0.3 m). The lake's earth-filled dam was later found to have sustained non-compromising damage to its concrete core and spillway.

Visible manifestations of Yellowstone's volcanic past and present appear across the park. Three calderas—

[5] Bozeman Daily Chronicle; 18 August 1959.

[6] http://www.westyellowstonenet.com/attractions/quake_lake_newspaper.htmef . Accessed 8/28/03.

resulting when a large volume of magma is removed from beneath a volcano, causing the ground to collapse into the empty space (Wright and Pierson 1992)—make up the park, the largest of which measures 28 mi wide by 47 mi long (45 km by 75 km) (USGS n/a). Calderas are dynamic, a reflection of ongoing tectonic, magmatic, and hydrologic changes (Newhall and Dzurisin 1988). Earth deformation and thermal activity (e.g., geysers, hot springs, and boiling mud pots), are common at calderas because of complex interactions among magma stored beneath calderas, groundwater, and a build up of stress in the Earth's crust. Surface and air temperature increases caused by geothermal features, plus briny discharge waters, significantly modify local atmospheric, terrestrial, and aquatic ecosystems.

Two examples of significant change in the Yellowstone caldera became apparent in the summer of 2003. Extreme surface heating (>200^{o}F [93 ^{o}C]) at Norris Geyser Basin caused park managers to close the area to protect visitors. Not far south, a bulge was discovered in the bed of Yellowstone Lake[7]. Spatial extent, periodicity, and ramifications of these events are unknown, though the possibilities of human catastrophe and a point-in-time ecological change from a violent earthquake or volcanic eruption make this a significant management issue. Such study is already underway at the Yellowstone Volcano Observatory (YVO), an interagency team of experts who monitor, among many things, seismic activity in the Greater Yellowstone Ecosystem[8].

Reduced stratospheric ozone: The thin air at high elevations allows a greater amount of solar radiation to reach high-alpine regions. Levels of ultraviolet light (UV), in fact, can differ by an order of magnitude between sea level and high-alpine environments (Caldwell et al. 1980). Alpine plants have adapted to high UV levels by either absorbing it in the epidermis or reflecting it off leaves.

During the second half of the 20th century, the level of UV reaching the Earth's surface increased due to the escape of chlorofluorocarbons (CFCs)—used for refrigerant and other purposes—into the atmosphere. CFCs catalyse the breakdown of stratospheric ozone, which absorbs UV before it can reach the Earth. While CFC use has largely been curtailed through the Montreal Protocol , the magnitude and ramifications of increased UV on biota remain, largely, a mystery. Alterations of high-elevation plant community structure, function, and survival are possible effects. UV-resistant evolutionary adaptations may eventually develop, but for such an acute, human-caused event, plant community changes may take place before adaptation occurs.

Carnivores have been called "umbrella", "keystone", and "flagship" species, as well as indicators of habitat or wilderness quality. Large carnivores, for example mountain lions in BICA or omnivorous grizzlies in the Greater Yellowstone Ecosystem, require large areas for hunting and foraging, and thus are particularly susceptible to the impacts of habitat fragmentation (Spowart and Samson 1986).

Occupying the top spot in the food chain, carnivores can have a powerful effect on trophic levels below them. In the wetlands ecosystem, for example, carnivores act as a stressor by directly influencing both beaver and ungulate populations, with a cascading effect on the makeup and extent of wetland vegetation. Carnivores can cause a decrease in beaver and ungulate populations, through direct predatory influences on these species. Thus, since beaver and ungulate grazing can severely disrupt the reproductive and growth capabilities of riparian plant species, the predation of these species can cause a resultant increase in riparian vegetative community reproductive success.

Beaver and ungulate grazing in riparian areas may disrupt the reproductive cycle of

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[7] See, for example, Bozeman Daily Chronicle, 17 August 2003.
[8] The YVO website can be found at http://volcanoes.usgs.gov/yvo/.

riparian trees such as cottonwoods, whose broad-leaved seedlings and saplings are extremely desirable forage. Removal of reproductive shoots also diminishes reproductive potential of willows (Kay 1994). Heavy ungulate use—whether wild or domestic—of floodplains and riparian areas may greatly reduce riparian ground cover, destabilize stream banks, and increase sediment loads to streams (Patten 1968; Armour et al. 1991; Elmore 1992; National Research Council [NRC] 2002). Wild ungulate use of wetland areas of YELL and GRTE has altered the cover and structure of the riparian community (Singer et al. 1994; Singer 1996; Keigley 1997). Recent reintroduction of wolves to the Northern Range in Yellowstone may reduce elk herds, thus allowing a resurgence of aspen. Given the complex web of interactions, this increase in aspen might, at least initially, result in the resurgence of depressed beaver populations.

C. SUMMARY

Conceptual modeling provides a valuable tool for identifying the important components of an ecosystem, the interactions among those components, how drivers and stressors impact the ecosystem, and what measurements are possible for determining ecosystem health. Additionally, conceptual modeling provided the Network these benefits:

- literature-based context for continued deliberations,
- multiple ecological frameworks as a basis for vital sign integration discussions,
- deliberate ecological assessment foundations with clear information legacy, and
- assessments of relevant spatial and temporal scales.

Importantly, the Greater Yellowstone Network conceptual modeling efforts described in this chapter (and in Appendix VI) revealed numerous potential vital signs not forthcoming from expert interview. A description of those potential vital signs and the process—including the Delphi Survey of subject-area experts, workshops, and Technical and Science Committee inputs—to select a final GRYN vital signs list are the topic of the next chapter.

III. VITAL SIGNS

Because the field of potential indicators to study is large, monitoring programs must select the best subset of those indicators for ecosystem study, working under such additional constraints as management relevance, budgetary limitations, and feasibility of implementation. The NPS has termed these ecosystem indicators "vital signs", reflecting their similarity to such critical human health measures as pulse and respiration. The analogy breaks down, however, because human vital signs are measurable metrics, whereas ecological vital signs, as presented in the I&M program, can also be stressors—in other words, processes or forcing functions that change health (consider diet in the human health parallel). All indicators selected for evaluation are vital signs, then, but not all vital signs are necessarily indicators.

> **Vital signs**
> The subset of physical, chemical, and biological elements and processes of park ecosystems that are selected to represent the overall health or condition of park resources, known or hypothesized effects of stressors, or elements that have important human values.

Vital signs may occur at any level of organization—landscape, population, community, or genetic—and may be compositional (referring to the variety of elements in the system), structural (referring to the organization or pattern of the system), or functional (referring to ecological processes). Given this complexity, selecting the best vital signs for monitoring ecosystem health requires a logical, step-wise process. The chapter that follows describes the selection process created by the GRYN, and then presents the Network's final list of vital signs for Phase II.

A. *IDENTIFYING* PROPOSED CANDIDATE VITAL SIGNS

The Greater Yellowstone Network took a two-pronged approach to identifying candidate vital signs, employing

- aquatic, terrestrial, and geothermal conceptual models, and
- scoping and outreach to scientists working in GRYN parks.

Chapter 2 addressed the GRYN conceptual modeling efforts, including the literature review that preceded each of the 14 models derived. The two sections that follow describe the Network's outreach efforts to solicit expert opinion for identifying potential vital signs.

1. THE DELPHI SURVEY PROCESS

In 2001 the GRYN cooperated with University of Idaho College of Natural Resources to conduct an Internet-based "Delphi" survey to help identify and rank the most important GRYN ecosystem components, conditions, and processes, and their indicators[9]. Over 400 experts—scientists and resource managers from GRYN member parks, neighboring agencies, academia, environmental groups, industry, and the private sector—were invited to participate. Over 100 individuals responded to the invitation.

The Delphi process consisted of three rounds of questioning, starting with general resource issues and culminating at specific monitoring needs. Delphi I and II were used to solicit input and rank resource components, conditions, and processes important in the GRYN. Delphi III asked the experts to rank the importance of ecosystem indicators derived from the resource components, conditions, and processes identified in Delphi I and II. This process

[9] The survey can be viewed on-line at http://www.its.uidaho.edu/wilderness/vsm .

resulted in a list of 188 possible indicators, ranked within subject areas, as can be seen in Appendix VII.

The Internet-based Delphi process has many *advantages* in identifying candidate vital signs, including that it:

- provides an easy way to obtain many ideas from a large audience,
- is rapid and efficient—participants can respond as their time is available,
- is resource efficient—no travel time or costs involved, and
- allows (forces) individual rather than group thought since the participants are dispersed in time and space.

The Delphi process used by the GRYN has *disadvantages*, as well, including that:

- participants can simply nominate any vital sign they choose, with no peer-reviewed evaluation as to merit or relevance of ideas,
- since the survey is voluntary, results will be skewed to the interests and expertise of those who choose to reply, and
- the results are not statistically defensible.

The full suite of *proposed* candidate vital signs for the GRYN was formed by combining the ranked vital signs from Delphi III with the vital signs identified in the conceptual modeling work. This proposed list was then evaluated against the Network's selection and prioritization criteria to derive the candidate vital signs list (done in a workshop forum, as described below).

2. Park Staff and Management Peer Review of Vital Signs Scoping Process

The GRYN Program Manger held park-specific workshops during March 2003 at GRTE and YELL. The purpose of these meetings was largely informational, covering three topics:

- bringing park staff up to date on the Service-wide and GRYN I&M programs, including progress on the Network's two methods for identifying candidate vital signs: conceptual modeling and the Delphi on-line survey,
- reviewing tables of threats and management issues for GRTE, some of which were stressors that needed to be included in conceptual modeling efforts, and
- presenting and testing the proposed criteria and process to rank and select vital signs from the list of proposed candidate vital signs.

Assembled staff and resource managers provided helpful input on threats and management issues facing the parks, engendering much useful discussion such as (a) can natural phenomena really be considered a "threat", or does "threat" only apply to human-caused stresses? and similarly (b) is global warming human-caused or natural? Conceptual modeling efforts were reviewed with respect to validity of spatial and temporal scale, and to unit of ecosystem organization. At Yellowstone, the results of the final Delphi questionnaire were reviewed and critiqued regarding the content of the Delphi-nominated vital signs list and the relevance of the values scored by the participants.

Peer review such as these park-specific workshops provides great benefits. *Peer review has been, and will continue to be, solicited by the Program Manager at all levels of development and implementation of the GRYN Monitoring Plan.* The outcome of peer review on the vital signs scoping process resulted in a shared and improved planning approach. Much useful critique centered on the Network's proposed selection process for choosing vital signs from the proposed candidate vital signs identified via conceptual modeling and the Delphi process. This critique substantially enhanced the process the Network used to prioritize candidate vital signs and then select the final vital signs, as is described in the following section.

B. *SELECTING* CANDIDATE AND FINAL VITAL SIGNS

Figure III.1 illustrates the GRYN process to select its vital signs. Two hundred and fifty (250) potential vital signs emerged from the combined conceptual modeling and Delphi survey efforts. Elimination of redundancies reduced the list to 196, which served as the starting point of the Network's Vital Signs Monitoring Workshop. Note that by helping the Network team visualize complex ecological interactions, the conceptual modeling work uncovered numerous vital signs not revealed via expert survey.

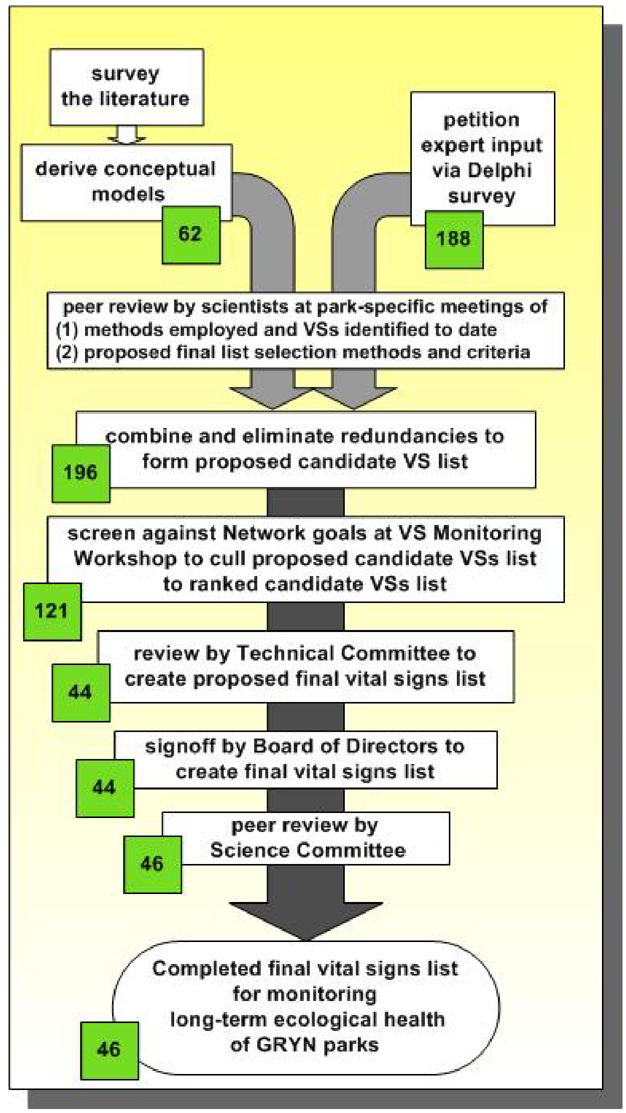

Figure III.1: Process for selecting GRYN vital signs (VSs). Numbers shown are vital signs remaining after each stage of the selection process.

1. <u>VITAL SIGNS MONITORING WORKSHOP (MAY 6-8, 2003)</u>

Under guidance from the National I&M Program, the GRYN hosted a Vital Signs Monitoring Workshop. The overall goal of the workshop was to reduce the list of 196 possible indicators to a manageable, cohesive set of indicators capable of monitoring long-term ecosystem health. To accomplish this task, the Network assembled 56 subject-area experts (Table III.1) and tasked them with prioritizing the list of candidate vital signs (note that this prioritization included combining vital signs to eliminate redundancies, reducing the list of 196 to 121 vital signs for consideration). Along with a focus on long-term ecosystem health and managerial relevance, this task required the subject-area experts to consider resource, time, and budget limitations.

To help guide the vital signs selection process, the workshop planning team created a list of 13 selection criteria, presented as yes/no questions (Table III.2) based on NPS I&M guidance and extensive literature review regarding what makes a "good" indicator. During day two of the workshop, break out teams of experts answered these 13 yes/no questions for each proposed candidate vital sign in their subject area (for example, terrestrial vegetation, invertebrate, and human use). A complete list of break out groups, including the subject-area experts, can be found in Appendix II.

By making the answers to these questions binary (yes/no) in nature, the workshop planning team believed they could minimize debates on semantics and scoring, thus enabling break out teams to complete their tasks of scoring many potential indicators in the time available.

The planning team's other objective was to turn the inherently *qualitative* process of selecting ecosystem indicators into a *quantitative* one. Thus the 13 selection criteria questions were grouped into five categories, with each weighted relative to its importance for a monitoring program (Table III.2). These categories (and weighting) were as follows:

Table III.1: Groups represented at the GRYN Vital Signs Monitoring Workshop. *

▪ BICA ▪ GRTE ▪ YELL ▪ Rocky Mountains-Cooperative Ecosystem Studies Unit ▪ National Park Service-Air Resources Division ▪ U.S. Geological Survey-Water Resources Disciplines ▪ U.S. Geological Survey-Northern Rocky Mountain Science Center ▪ Environmental Protection Agency ▪ Greater Yellowstone Coordinating Committee ▪ U.S. Forest Service	▪ Wyoming Game and Fish ▪ Snowcap Hydrology ▪ Yellowstone Ecological Research Center ▪ Montana Natural Heritage Program ▪ Montana State University ▪ Montana State University -- Big Sky Institute ▪ Idaho State University ▪ Iowa State University ▪ University of Oregon ▪ University of Montana ▪ University of Wyoming ▪ Wyoming Natural Diversity Database ▪ Thermal Biology Institute

* For a complete list of participants and contact information, please see Appendix II.

(1) *Ecological relevance (25%)*—Does the vital sign help us understand long-term ecosystem health?

(2) *Response variability (25%)*—Is the vital sign tightly coupled to, and preferably anticipatory of, the change(s) occurring?

(3) *Managerial relevance (20%)*—Does the vital sign address current or foreseeable management issues?

(4) *Feasibility of implementation (15%)*—Can the vital sign be measured at a reasonable cost, and can sampling protocols be designed to eliminate personnel-induced variability?

(5) *Interpretation and utility (15%)*—Can the vital sign differentiate between natural and anthropogenic change and identify the cause of ecosystem change?

A scoring system, essentially[10] as follows, was then devised that quantified the group's expert

$$\textbf{vital sign ranking} = \sum_{n=1}^{5} \left\{ \frac{\textbf{(\# "yes" answers per category)}}{\textbf{(\# questions per category)}} \right\} \textbf{ x } \textbf{(category weight)}$$

knowledge regarding the ability of a potential indicator to address the 13 desirable vital signs criteria.

[10] For a more complete description of scoring method, see Appendix II.

Table III.2: Selection criteria applied to each of the 121 candidate vital signs, plus the weighting assigned to each criteria category.

Category (weight)	Criteria (yes or no?)
Ecological Relevance (25%)	1. The candidate vital sign has high ecological importance with a demonstrated linkage between the vital sign and the ecological structure or function that it is supposed to represent, based on a conceptual model and/or supporting ecological literature. 2. The candidate vital sign provides relevant information that is applicable to multiple scales of ecological organization.
Response Variability (25%)	3. The candidate vital sign responds to ecosystem stressors in a predictable manner with known statistical power. 4. The candidate vital sign is anticipatory and is sensitive enough to stressors to provide an early warning of change. 5. The candidate vital sign has low natural variability and has high signal-to-noise ratio (e.g. low error) and/or supporting ecological literature.
Management Relevance (20%)	6. The candidate vital sign is stated in specific park management goals, GPRA goals, or Business Plan standards. 7. There is a demonstrated, direct application of candidate vital sign measurement data to current key management decisions or for evaluating past management decisions.
Feasibility of Implementation (15%)	8. The candidate vital sign's cost of measurement is not prohibitive. 9. Impacts of measuring the candidate vital sign meet NPS standards. 10. The candidate vital sign is relatively easy to measure and has measurable results that are repeatable with different personnel.
Interpretation and Utility (15%)	11. The response of the candidate vital sign can be distinguished between natural variation and anthropogenic impact-induced variation. 12. The candidate vital sign is helpful in identifying the causal mechanism of an ecological response. 13. Historic databases and baseline conditions for the candidate vital sign are already known.

The subject-area experts answered the 13-yes/no criteria for each proposed candidate vital sign in their area on worksheets. As each worksheet was completed, results for the proposed candidate vital sign were entered into an Access database for calculation of the equation above. Thus, each proposed candidate vital sign received a score of between 0 (not important) to 1.0 (most important).

Entry of the subject-area expert responses into the Access database decision support system was completed overnight. On the final morning of the workshop, then, the Program Manager presented the ranked list of 121 candidate vital signs to the participants (the full list is available in Appendix II). This rapid turnaround allowed the workshop participants to review and critique the methods and results of the prioritization process. These critiques, which serve as a valuable resource to other networks just beginning I&M scoping, can be found as part of the full workshop report in Appendix II.

2. TECHNICAL COMMITTEE SELECTION PROCESS

In June 2003, a month after the Network's ranked list of 121 *candidate* vital signs was created, the GRYN Technical Committee (TC) met for three days to select the Network's proposed *final* vital signs. The TC, which is made up of park personnel and other NPS personnel, serves as the main advisory body to the Program Manager. The TC's park-specific expertise was critical to the vital signs selection process since many of the participants involved in the steps leading up to, and including, the Vital Signs Monitoring Workshop were not NPS employees. Thus, while the I&M program goals addressing ecosystem relevance (Table I.6) were covered in the selection process to date, management relevance was often lost in the numerical ranks. For example, during the Vital Signs Monitoring Workshop, many participants expressed concern with their inability to rank the questions pertaining to management relevance because they were not NPS employees.

Technical Committee approval of the vital signs list also served as an important checkpoint for the GRYN Board of Directors (BOD), whose sign-off was required to make the Network's list officially "final". The Board relies heavily on Technical Committee guidance, since the TC has been an integral part of the planning process for the GRYN and, hence, has a more intimate, day-to-day knowledge of the structure and purpose of the Network.

To start the meeting, the Program Manager decided to use the ranked list of candidate vital signs from the Vital Signs Monitoring Workshop, mainly because it presented a compilation of the data from the different input sources to date. In addition to using the ranked list, the Program Manager decided to present only the vital signs ranked "0.9" or higher, somewhat as an arbitrary cut-off point, yet a reasonable starting point for discussion. This cut-off reduced the list to 40 candidate vital signs.

Figure III.2 shows the TC selection process, beginning with the 40 candidate vital signs. First, the TC was invited to add candidate vital signs from below the cut-off point, given their belief in the importance of the vital sign to monitoring long-term ecosystem health and/or to management policies. This step allowed for the addition of candidate vital signs that may have ranked lower during the Vital Signs Monitoring Workshop due to lack of information or knowledge on their management relevance. Moreover, TC nominations were also meant to quell concerns raised after the Vital Signs Monitoring Workshop that the break out groups used different thresholds for ranking the proposed candidate vital signs.

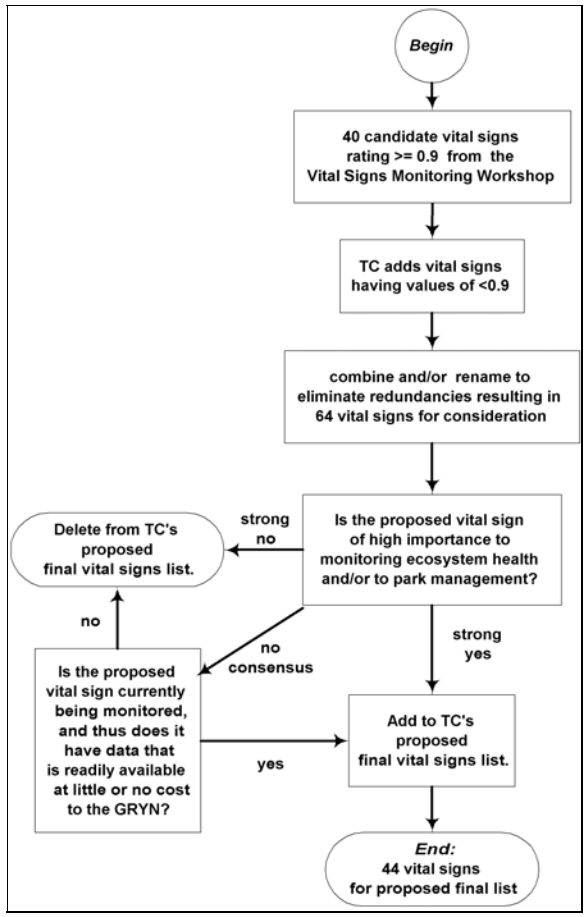

Figure III.2: Technical Committee process for selecting proposed final vital signs list.

Next, the TC combined and/or renamed vital signs whose meanings were similar. Many times proposed candidate vital signs nominated by the Delphi process and the conceptual models had similar meanings but were written in slightly different vernacular, depending upon the background and expertise of the nominator. Following this combining process, 64 vital signs remained for continued consideration.

The TC then addressed each of the 64 vital signs individually, first considering whether the vital sign was of high importance to monitoring ecosystem health and/or to park management. Potential vital signs that the TC *strongly* agreed did or did not meet this screen were respectively selected for, or dropped from, the proposed final vital signs list.

For candidate vital signs where strong group consensus was *not* achieved, the TC members turned to the question of data and funding availability for the vital sign to determine if the Network's limited funds could be leveraged using monitoring programs already underway. Those vital signs with ongoing programs were added to the proposed final list of vital signs; the rest were dropped.

Application of the two screening questions reduced the list of 64 candidate vital signs to 44, the TC's proposed final vital signs list to be later submitted (August 2003) for BOD approval.

This decision process seemed to work well with the members of the TC in that:

- each park was given a chance to air park-specific concerns that may not have been otherwise addressed,
- each park was given equal input into the process, and
- funding concerns were *not* considered unless there was a disagreement on the importance of the candidate vital sign, thus allowing for the formation of an integrated list that was not dependent upon current funding possibilities.

The final point regarding funding is important; by keeping funding largely out of the selection criteria, the Network was assured of creating a proposed final vital signs list fully relevant to monitoring long-term ecosystem health and/or to management concerns.

C. GRYN VITAL SIGNS LIST

Table III.3 shows the proposed final GRYN list of 44 vital signs resulting from the TC selection meeting[11]. By monitoring this list of vital signs, then, the Network believes that it can effectively assess the long-term ecosystem health of its parks.

In Phase III of the program, the Network will develop monitoring objectives and sampling protocols, then allocate funding for monitoring a subset of the selected vital signs. The Program Manager and TC recognized that funding and resource constraints will play a large role in determining the start up (and ongoing progress) of the Network's monitoring program. Thus, while all 44 vital signs are considered as important to assessing long-term ecosystem health, the Program Manager requested that the TC provide guidance regarding monitoring prioritization of each vital sign. After considerable discussion and debate, the vital signs were broken into four categories as a basis for Phase III program design and budget allocation, as described in the Table III.3 key. The TC recommended 11 vital signs as top priority for Network monitoring.

1. Ecological and Managerial Relevance

Several monitoring themes, as shown in Table III.4, emerge upon review of the selected vital signs. Taken as a group, the themes show that the vital signs selected integrate across biologic, aquatic, and geologic boundaries, plus keep sight of park management issues.

During the selection process, the TC continuously focused on the ecological relevance of the candidate vital signs. Review of the Network's selected vital signs list (Table III.3) reveals this focus—the vital signs selected cross many environments, including atmospheric, terrestrial, aquatic, and geologic regimes, each of which includes an anthropogenic element. The Network created a conceptual framework as a tool to help reveal ecological relevance.

[11] The list was approved one month later by the Board of Directors (see section III.D). The approved list of vital signs was later slightly modified as a result of peer review by the Science Committee. The Program Manager used a BOD-agreed-upon process to make two additions and modify several vital signs names for clarity. Details of these modifications, along with the Network's final vital signs list for beginning Phase III, are provided in section III.E (Table III.5).

Table III.3: Technical Committee's recommended list of 44 vital signs for the GRYN. Reasons for vital sign selection are cataloged for each Network park, with a key listed at the bottom of the table.

Resource / ecosystem domain	Selected vital signs	BICA	GRTE	YELL
Aquatic	Watershed budgets	4	4	4
	Continuous water temperature	3	3	3
	Groundwater quantity and quality	4	4	4
	Reservoir elevation	2	2	
	River invertebrate assemblages	1.a.b	1.a.b	1.a.b
	Springs and seeps distribution and hydrology	1.a.b	1.a.b	1.a.b
	Stream flow	1.b	1.b	1.b
	Water chemistry	1.a.b	1.a.b	1.a.b
Aquatic Biotic	Algal species composition and biomass	4	4	4
	E. coli *(Escherichia coli)*	3		
	Exotic aquatic community structure and composition		1.a.b	1.a.b
	Native aquatic community structure, composition, stability and genetic integrity	3	3	3
Atmospheric	Atmospheric deposition of nitrogen, sulfur and all major anions and cations (including wet and dry deposition)	4	4	3
	Change in visibility deciviews	4	4	3
Climatic	Basic climatological measurements	1.b.c	1.b.c	1.b.c
	Glacial retreat or advance		3	
Geologic (geothermal)	Earthquake activity		2	2
	Geothermal feature abundance and distribution		3	3
	Geothermal water chemistry		4	4
	Heat flow / chloride flux		1.a.b	1.a.b
	Soil structure and stability (includes cryptogamic crusts)	4	4	4
	Stream sediment transport	4	4	4
Human	Land-use change and habitat fragmentation	1.a.b.c	1.a.b.c	1.a.b.c
	Levels of backcountry day use		2	2
	Levels of backcountry overnight use		2	2
	Oversnow vehicles emissions		2	2
	Soundscapes	4	2	2
	Visitor use levels	2	2	2
Terrestrial Biotic	Amphibian occurrence	1.b	1.b	1.b
	Beaver presence and distribution	4	3	2
	Browse effects on riparian woody vegetation	3	3	3
	Communities of concern (riparian, shrub-steppe, aspen, and alpine communities)	4	3	3
	Exotic plant species abundance and distribution	1.a.b	1.a.b	1.a.b
	Fire, fuels and carbon storage	3	3	3
	Forest insect and disease	4	3	2
	Land bird distribution and abundance	3	3	3
	Land-cover classification	3	3	3
	Large carnivore population distribution and abundance	3	3	3
	Meso carnivore population presence and distribution	3	3	3
	Native insect diversity and distribution in riparian and mesic meadows	4	4	4
	Selected sensitive bird species abundance, distribution, and productivity	2	2	2
	Ungulate population distribution and abundance	2	2	2
	Vertebrate diseases	4	3	3
	Whitebark pine decline		1.b	1.b

<u>Basis of selection</u>

1. Considered by TC as highest priority (top 11 vital signs) because they fit one of the following criteria:
    a) basic, critical information needed to make decisions
    b) information that helps the Network describe and understand the broader system
    c) managerial-driven information needs (e.g., T&E or snowmobiles)
2. Vital signs for which at least a minimally acceptable monitoring program is in place.
3. Some work is being done; however, only *part* of the vital sign is being monitored or more work is necessary.
4. Very little work is being done; might need an inventory before a monitoring program can be developed.

This framework (Figure III.3) depicts the interrelationships among the 44 selected vital signs, placing them within multiple ecosystem domains. Figure III.3 shows that critical ecological issues operating at large temporal and spatial scales—e.g., climate dynamics (via climate and glacier monitoring), landscape fragmentation, and geologic/geothermal activity—are well represented. More localized issues—e.g., stream flow and amphibian occurrence—are also covered. It is important, also, that the selected vital signs include ecosystem stressors (for example, forcing functions such as landscape change and habitat fragmentation) as well as response variables (such as river invertebrate assemblages).

Table III.4: Ecological themes of vital signs selected for GRYN monitoring.

Climate
Disease and Exotics
Human impacts
Park specific issues: * Geothermal * Soils and seeps
Species and communities of concern
Air quality
Water quality

Vital signs addressing concerns particularly relevant to park managers are also well represented in the TC's vital signs list, with all Network parks duly represented. Examples of vital signs relevant to management include monitoring for human impacts (e.g., visitor use levels, over snow emissions and effects), disease (e.g., brucellosis, whirling disease, blister rust), invasive species (e.g., mud snails, spotted knapweed), species and communities of concern (e.g. selected sensitive bird species, vegetative communities), fires, fuel, and water quality. This final theme is highlighted in the following section, as requested by the National Program.

2. <u>Water Quality Issues</u>

Several vital signs will be used to detect improvements (or lack thereof) in water quality related to state 303(d) streams, plus enable park managers to report on progress towards GPRA goal 1.a.4—that the parks have unimpaired water quality by 2005. In Bighorn Canyon, the Shoshone River appears on Wyoming's 2002 303(d) list for concerns related to fecal coliform contamination. *Escherichia coli* (*E. coli*), a bacterium used to assess water safety for body contact recreation or for consumption, has been selected as a vital sign by the Network. The presence of *E. coli* in water is direct evidence of fecal contamination from warm-blooded animals and indicates the possible presence of pathogens (Dufour 1977).

Excesses in nutrient loading was cause for Montana to list the Bighorn River from Yellowtail Dam to the Crow Indian Reservation Boundary as a 303(d) stream in 2002. Water chemistry, a selected vital sign that includes nutrients, will be used to monitor nutrient loading along the Bighorn River.

Reese Creek is also on Montana's 303(d) list due to dewatering and flow alterations. This stream is heavily dewatered in its lower reaches during the period in which Yellowstone cutthroat trout are typically making spawning migration runs (Mahoney 1987). Stream flow, also selected as a vital sign, has been monitored at Reese Creek since 1984 when a Parshall flume and gauges were installed along Yellowstone Park's northern boundary.

Soda Butte Creek is on Montana's 303(d) list due to metals contamination from the McLaren mine tailings outside Yellowstone National Park. Although considered as a candidate vital sign, metals were not selected by the TC. In this case, as in all regulatory monitoring, strategies will be designed to determine if state water quality standards continue to be exceeded and to detect improvements. In part, the parameters to be monitored for regulatory purposes are dependent upon the specific criteria used by the state to define use categories or classes of its surface waters. These parameters may or may not correspond to GRYN selected vital signs.

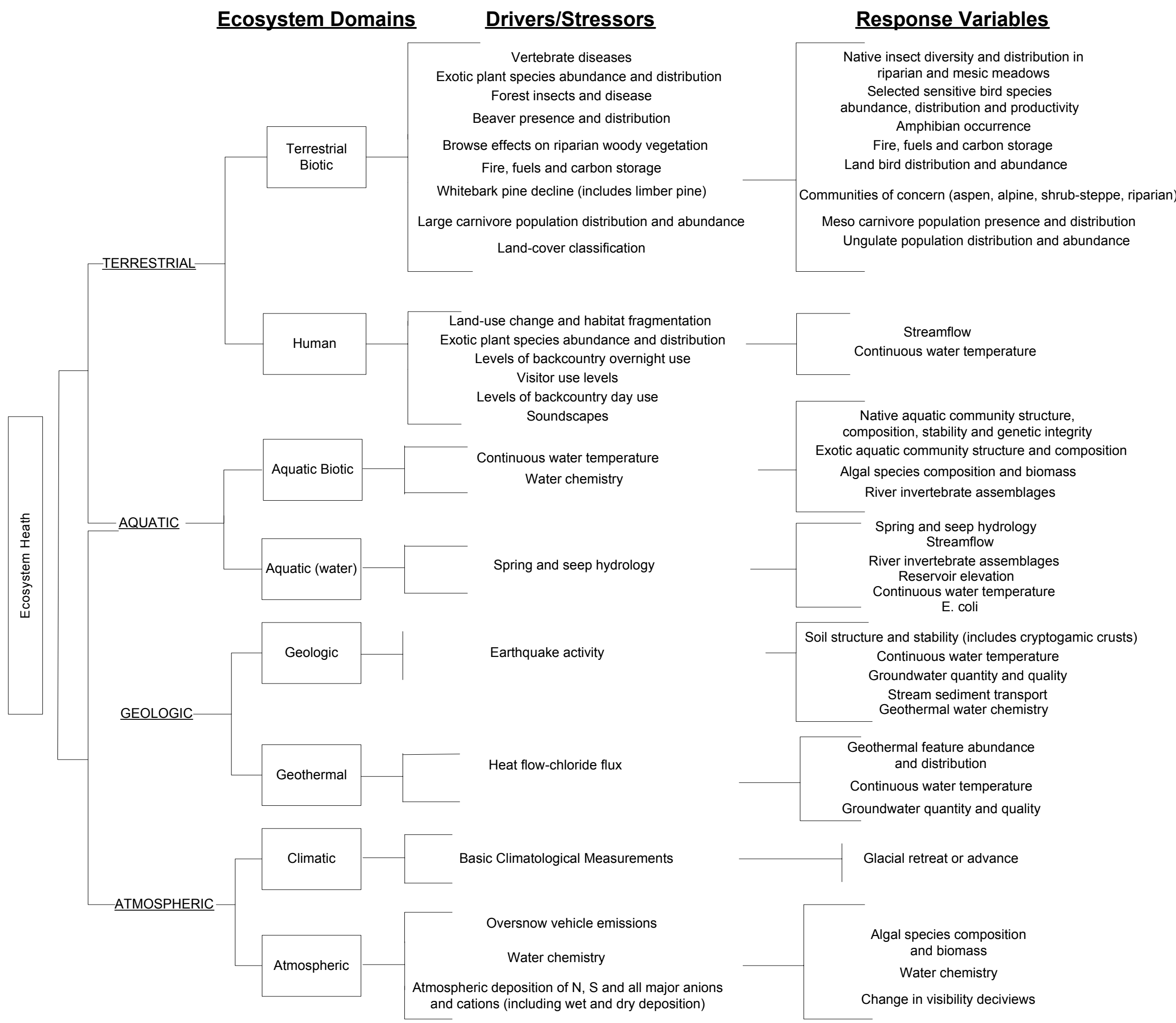

Figure III.3: Conceptual framework showing the TC's recommended 44 vital signs for the GRYN.

3. VITAL SIGNS THAT WERE NOT SELECTED

Many of the original *candidate* vital signs were not selected for the GRYN Vital Signs Monitoring Plan. The numerical ranks of the vital signs not selected ranged from high to low. A few unselected vital signs scored greater than 0.9. The TC recognized these as important indicators in some ecosystems but, after due consideration, opted to leave these vital signs off the final list.

Invasive terrestrial vertebrates, for example, were not as a group chosen as a vital sign. However, by monitoring the species richness and distribution of invasive vertebrate species, the status and trends of these populations, as well as the effectiveness of current management techniques and possible preventative actions, can be determined (NPS 1997). Invasive species of special interest to workshop participants included bullfrogs, raccoons, English sparrows, starlings, pigeons, turkeys, pheasants, mute swans, and feral cats. While the general category of invasive terrestrial vertebrates was not selected, two species—lake trout and bullfrogs—will be monitored as a part of other vital signs that were selected.

Other highly ranked vital signs not selected by the TC include:

- *Lichen distribution, abundance, and chemical composition:* Lichens can be highly important where air pollution is a major problem. The National Academy of Sciences Committee has suggested that lichens are an important component of vegetative communities.
- *Wetland extent:* This candidate vital sign refers to the area of the wetland as well as its major components. Wetlands comprise 94 million acres (38 million ha) in the United States today, signaling a decrease of approximately 50% from pre-settlement times. A change in the extent of an ecosystem signals the loss of the associated species and services that the ecosystem provides. Loss of wetlands also can lead to increased flooding (Heinz Center 2002).
- *Whitebark pine cone production:* The production of whitebark pine cones, and therefore seeds, is critical forage for both Clark's nutcrackers and grizzly bears, as well as for the reestablishment of whitebark pine at both high and low elevations (Tomback et al. 2001). In addition, reduction of cone production can be an early indicator of infection by white pine blister rust, which often kills cone-bearing branches prior to killing the entire tree (Tomback et al. 2001).

The remaining candidate vital signs (ranked <0.90) that were not selected by the TC fall into three categories:

(1) Those physical in nature, such as landslides and debris flow, stream channel change, stream reach geomorphology, hydrologic modification, and geyser eruption volume and rate.

(2) Those biological in nature, such as zooplankton, reptiles, rodents, lagomorphs, and geothermal microbial diversity

(3) Those chemical in nature, such as nitrogen in grass and shrublands, deposition and accumulation of mercury in biota, geothermal gaseous emissions, soil chemistry, metals in rivers and streams, and bed sediment chemistry.

For a complete list of nominated vital signs and their numeric rank see the Vital Signs Workshop Report (Appendix II).

4. BRIEF DESCRIPTIONS OF GRYN VITAL SIGNS

On the following pages, we provide short descriptions or measurement methods for each of the vital signs selected for the GRYN Vital Signs Monitoring Program. Greater detail can be found in the technical notes created for each vital sign (see Appendix VIII). Note that the vital signs are presented in the same order as in Table III.3.

- **Watershed budgets** are a compilation of water, nutrient, sediment, and chemical inputs and outputs for a particular watershed. These budgets are variable depending on the study area; however, most sample for concentration of major ions and isotopes, stream flow, groundwater hydrology, and continuous temperature. Watershed budgets are one method for monitoring water quality in the GRYN.
- **Continuous water temperature:** Because temporal variation in temperature can be significant, intermittent temperature monitoring (stations) can be problematic. Thus, use of continuous recording devices is a preferred means of eliminating time-associated sampling problems. All temperature measurements should be made and reported in units of degrees Celsius (ºC). All temperature measurements should be reported to the nearest 0.2ºC when using a thermistor thermometer and to the nearest 0.5ºC when using a liquid-in-liquid thermometer.
- **Groundwater quantity and quality** refers to the groundwater level and chemistry (including contamination). This information can be obtained through purging and sampling of groundwater wells, including data such as groundwater level and volume, pH, temperature, conductivity, and trace organic compounds and metals (MTDEQ 1995).
- **Reservoir elevation:** Lakes that are hydrologically managed will have fluctuating water levels that can potentially affect lake food webs and ecosystem function and, therefore, need to be monitored for elevation changes, reservoir storage, inflow, and outflow. The Bureau of Reclamation measures the reservoir elevation of both Jackson Lake and Bighorn Lake (Yellowtail Dam) and provides information on its website such as pool elevation (in feet), reservoir storage (in acre-feet), and inflow and outflow (in cfs).
- **River invertebrate assemblages:** The composition of invertebrate assemblages can indicate water quality and may change in response to exotic species, sedimentation, nutrient load, predator population change, and/or climate change. Sampling can occur according to two methods: comparing measured assemblage structure with species that may be indicative of water quality (e.g., Stribling et al. 1999), or using multivariate approaches to estimate predicted invertebrate assemblages that can be compared to measured assemblage structure.
- **Springs and seeps distribution and hydrology** include the location and the volume, duration, and seasonality of flow of springs and seeps located primarily within BICA, and somewhat within the boundaries of GRTE. This vital sign is quantified by calculating the physical/geometric measurements (maximum, minimum, and average depth, length, and width of the surface water) and discharge (flow duration, peak flows, and flow quantity) at each spring or seep.
- **Stream flow**, also known as stream discharge, is the measure of the flow of water in a stream at a specific time, including (1) routing mechanisms in a watershed and water quality at that time, and (2) land-use activities, point-source discharges, and natural sources. Stream discharge (Q) is defined as the unit volume of water passing a given point on a stream or river over a given time. It is typically expressed in cubic feet per second (cfs) or cubic meters per second (cms), and is based on the equation:

  $$Q = A * V$$

where A is the cross-sectional area of the stream at the measurement point and V is the average velocity of water at that point.

- **Water chemistry:** Information from monitoring water chemistry is used to evaluate stream condition with respect to such stressors as atmospheric deposition, nutrient enrichment, and other inorganic contaminants. The following parameters and ions are usually monitored: alkalinity, ammonia, bicarbonate, carbonate, calcium, chloride, fluoride, iron magnesium, manganese, nitrate, pH, potassium, silica, sodium, sulfate, total dissolved solids, total suspended solids, and total nitrogen and phosphorous (reported in micro or milligrams per liter). Concurrent discharge measurements allow data to be presented as mass flows (e.g., g/hr).
- **Algal species composition and biomass:** Algal species composition refers to the kinds of species present in a body of water, while algal biomass is the combined mass of these species. Certain species can indicate changes in the water column, such as increased nutrient input or water temperature. Algal composition is measured by examining algal assemblages, and algal biomass can be measured using chlorophyll A concentrations or Secchi disk measurements (for water clarity).
- ***Escherichia coli (E. coli*)** is one type of fecal bacteria that is used for predicting gastrointestinal illness in swimmers based on the density of the indicator organism in bathing waters. The EPA estimates that no more than a geometric mean of 126 *E. coli* per 100 ml of fresh water should be present to be protect people from gastrointestinal illness. The Shoshone River is listed as a 303(d) stream due to its high levels of *E. coli*.
- **Exotic aquatic community structure and composition** includes the number of exotic fish species (e.g., lake trout in Yellowstone Lake), as well as invertebrates (e.g., the New Zealand mud snail), that are causes of concern in park aquatic ecosystems. Monitoring the distribution (geographical location), abundance (number at each sampling location), and spread of the species will allow managers to understand the environmental consequences of these communities.
- **Native aquatic community structure, composition, stability and genetic integrity** refers to the overall health of the fish communities in water bodies of interest. To measure native aquatic health, species richness, and composition metrics, trophic composition metrics, fish abundance, condition metrics, and genetic purity analysis must be performed.
- **Atmospheric deposition of nitrogen, sulfur, and all major anions and cations (including wet and dry deposition):** Atmospheric deposition is the process whereby precipitation (rain, snow, fog), particles, aerosols, and gases move from the atmosphere to the earth's surface. This vital sign is quantified by measuring snowpack chemistry and direct measurements of wet (NADP/NTN) and dry (CASTNet) deposition.
- **Change in visibility deciviews:** This vital sign refers to people's ability to view a scene unaffected by anthropogenic emissions, such as sulfur, nitrogen, and organic pollutants. The National Park Service is required by the Clean Air Act Amendments to prevent significant deterioration in air quality and its effects, with an emphasis on visual air quality or visibility. The NPS has certified that visibility is impaired in all Class 1 areas, including GRTE and YELL. BICA is a Class 2 area, requiring some level of air quality protection. Visibility is currently being monitored in Yellowstone only, as part of the Interagency Monitoring of Protected Visual Environments. This monitoring includes the collection of size-selected particles, which are then analyzed for chemical composition. These visibility-reducing particles are usually less than 2.5 microns in diameter. They scatter and absorb light before it reaches human observers, resulting in a "hazy" scene. The metric that is constructed from particle counts and size fractions is known as "extinction", which, in turn is used to calculate the "deciview".

- **Basic climatological measurements:** Climate is the "long-term characteristics of weather" (NOAA 2003). Basic climatological measurements include: temperature (maximum, minimum, and average), precipitation, relative humidity, wind, surface pressure and snow cover, depth and water equivalent. The following are recommended standard metrics for these climatological variables: air temperature (°C), surface wind (m/s), atmospheric humidity/water vapor in percent (%) or mixing ratio in g H_2O/kg-air or concentration in g H_2O/m^3, surface pressure (hectopascals [hPa] or millibars [mb]), snow cover and depth (water equivalent) per km^2 and/or percent of area for cover and mm/cm for depth.
- **Glacial retreat or advance:** Glacial advance occurs when a mountain glacier's terminus extends farther down valley than previous measurements, while glacial retreat happens when the position of a mountain glacier's terminus is farther up valley than previous measurements or when a glacier ablates more material at its terminus than it transports into that region (NSIDC 2003). The likelihood of an advance or retreat is measured by calculating the net mass balance (in m) of the glacier over time. Mass balance is calculated by monitoring accumulation (where snowfall exceeds snowmelt) and ablation (where snowmelt exceeds snowfall) with respect to preset levels. After numerous years of positive mass balance, the glacier will advance; after years of negative mass balance, glacial retreat occurs (USGS 1997).
- **Earthquake activity** refers to the frequency, magnitude and location of earthquakes. Information on specific locations (latitude, longitude and location), date (month, day, year), time, depth (m), and magnitude (according to the Richter scale) are available through the Yellowstone Volcano Observatory using the University of Utah seismograph stations. Earthquake monitoring is needed both as adjunct to monitoring for volcanic activity and along fault lines for patterns of seismicity in time and space, direct measure of seismic activity, and changes in seismic activity.
- **Geothermal feature abundance and distribution** refers to the number and location of geothermal features, including mud pots, geysers, fumaroles, neutral chloride thermal springs, and acid sulfate thermal springs.
- **Geothermal water chemistry** refers to the monitoring of water chemistry, especially cations (As, F, Hg), and chloride concentrations in geothermal areas, along with temperature and associated volume and flow patterns. These measurements should be measured according to USGS-NAWQA standards.
- **Heat flow / chloride flux:** Heat flow refers to the heat that is transmitted from the hot interior of Earth to the surface in a specified time across a specified area. Increased heat flow in an area indicates possible changes in subsurface hydrothermal activity. Remote sensing is a cost-efficient method to map and monitor heated ground. The chloride flux method for estimating heat flow in YELL has been extensively peer reviewed, accepted, and published. The Yellowstone Volcano Observatory (YVO) (2003) uses the chloride concentration upstream (Cl_u) and downstream (Cl_d) of the hot springs, the chloride concentration in the thermal water (Cl_t), and the discharge rate of the stream (Q_s) to calculate the discharge rate of a hot spring group (Q_t):

  $$Q_t = [Q_s\,(Cl_d - Cl_u)] \;/\; [Cl_t - Cl_{bkgd}]$$

  where Cl_{bkgd} is the background chloride concentration upstream of any thermal source and assuming that $Q_t << Q_s$ and $Cl_t >> Cl_u$.
- **Soil structure and stability (includes cryptogamic crusts):** Soil structure and stability is the physical, chemical, and biological characterization of soils within the GRYN. Of

particular interest is the soil structure and stability within the boundaries of BICA, where cryptogametic crusts represent the majority of the living ground cover. This vital sign is quantified by calculating one or more physical, chemical, or biological properties that are sensitive to change.

- **Stream sediment transport:** Sediment data, both suspended and channel bed, is necessary to evaluate sediment yield with respect to background environmental conditions (geology, soils, climate, runoff, topography, ground cover, and size of drainage area), historic and current land uses, and erosion and deposition in channel systems. Additionally, the understanding of the temporal distribution of sediment concentration, size characteristics, and transport rates is crucial to the management of instream aquatic communities and riparian ecosystems. Standardized sediment sampling methods and frequency of collection will be dictated by the hydrologic and sediment characteristics of the water bodies to be sampled in the GRYN (which will vary greatly), the required accuracy of the data, the funds available, and the proposed use of those data collected.
- **Land-use change and habitat fragmentation:** Fragmentation is the process that occurs when a habitat or land-cover type is subdivided either by a natural disturbance or by human activities, including, in part, urban and suburban development, roads, farmlands, and railroads. Remote-sensing data are useful for determining the extent of landscape and habitat fragmentation. Analyses on forest cover have used the USGS's National Land Cover Dataset, a 30-m (98 ft) resolution remote sensing dataset. Possible analysis techniques include the "moving window" technique, described by the Heinz Center (2002). See also land-cover classification.
- **Levels of backcountry day use:** The level of backcountry day use is the number of individuals who use backcountry areas within park boundaries but do not stay overnight. This measurement is difficult to obtain and may involve the use of site-specific measurements or calibrated trailhead registers.
- **Levels of backcountry overnight use:** The level of backcountry overnight use is the number of individuals who use backcountry areas within park boundaries and stay overnight. This measurement can be made by using the number of backcountry permits sold.
- **Oversnow vehicle emissions** are the chemical deposition of particles and gases from snowmobile exhaust into snowpack. Snowpack chemistry (concentrations of organic and inorganic compounds) is used as a metric for snowmobile emissions.
- **Soundscapes** refer to natural and human-made sounds that disturb the natural quiet of an area. Particularly important for GRTE are the human-made sounds produced by the airport that qualify as "noise" under the following definition from NPS management policies: "Noise is generally defined as an unwanted or undesired sound, often unpleasant in quality, intensity or repetition." In Denali National Park and Preserve, sound level meters and digital media storage devices are used to record sound level in decibels (dB). Digital sound recordings can also be used to monitor soundscapes.
- **Visitor use levels** refer to the total number of visitors using specified areas within park boundaries. Many times this information also includes visitor satisfaction data. These data are generally collected through site-specific or automobile survey.
- **Amphibian occurrence** is the population status and trends of amphibians throughout the GRYN. This vital sign is quantified by calculating the proportion of wetland sites occupied by amphibians per water catchment, also known as the proportion of area of sites occupied.
- **Beaver presence and distribution:** Beaver presence refers to the presence or absence of

beaver at selected sites to be resampled every 2-5 years, while beaver distribution refers to locations of known beaver activity across park landscapes. Presence/absence data are initially collected at chosen sites throughout the parks, followed by regular resampling. Distribution measurements employ GPS data points from presence/absence datasets to show the distribution of beaver activity across the landscape.

- **Browse effects on riparian woody vegetation** are the impacts of ungulate grazing on riparian species such as willow and aspen. Browse effects can be measured by creating wildlife exclosures in high- and low-use areas across riparian vegetation types, and by conducting plant cover sampling.
- **Communities of concern (alpine, aspen, shrub-steppe, riparian):** Vegetation composition and structure in terrestrial communities of concern refers to the species makeup of areas of concern in the GRYN, including alpine, aspen, shrub-steppe, and riparian areas. Methods to measure this indicator are generally comprised of belt transects and/or quadrat studies, including total species present and percent cover in relation to expected species present. However, in some cases (e.g., sage grouse and bird species in riparian areas), the indicator measured will be a vertebrate species or the soil structure of the ecosystem.
- **Exotic plant species abundance and distribution:** Under Executive Order 13112 (1999), the official definition of an invasive species is "an alien species whose introduction does or is likely to cause economic or environmental harm or harm to human health." Meanwhile, the NPS Management Policies define invasive species as "those occurring outside their native ranges in a given place as a result of actions by humans," thus differentiating between human-caused invasions and those occurring due to natural processes.
- **Fire, fuels, and carbon storage** refers to the cyclical relationship between these three ecosystem components and their interrelated effects on each other. Large-scale modeling of the effect of fire on carbon storage and fuel loads, using remote sensing techniques, will allow for the creation of models that indicate the link between carbon levels, land-use change and climate change.
- **Forest insects and disease** refers to a variety of insect species and diseases that are problematic throughout the GRYN, including, but not limited to, spruce beetle, mountain pine beetle, gypsy moths, spruce budworm, tussock moths, annosum root rot, and blister rust. Monitoring programs for these insects and diseases generally consist of detection and survey phases (i.e., pheromone traps), aerial surveys (to detect large areas of defoliation), and ground survey.
- **Land bird distribution and abundance:** Most bird species, other than those selected as "sensitive", are included in this vital sign (e.g., colony nesting birds, songbirds, and migratory birds). Land birds should be monitored for abundance and distribution using distance sampling (line transect or variable circular plot sampling or double-observer methods) and nest productivity using constant-effort mist netting and banding (such as that used by the MAPS program) (Fancy 2003).
- **Land-cover classification:** Using differences in infrared wavelengths emitted by vegetation, it is possible to classify landscape heterogeneity using Landsat 5 images, eliminating costly groundwork and, therefore, allowing the parks to follow changes in vegetation cover.
- **Large carnivore population distribution and abundance:** Large carnivore abundance refers to the number of large carnivores at selected sites to be resampled, while large carnivore distribution refers to locations of the large carnivores across park landscapes.

Abundance data are initially collected at chosen sites throughout the parks and resampled, and distribution measurements should include GPS data points of where abundance data were collected to show a landscape distribution of large carnivores. Data collection is already being performed to some degree by the parks, along with other federal and state agencies, and non-government organizations.

- **Meso-carnivore population, presence, and distribution** is the population status and trends of small to mid-sized carnivores throughout the GRYN, such as lynx, wolverine, fisher, marten, bobcat, Swift fox, and river otter. This vital sign is quantified by calculating the presence/absence, relative abundance (density), and absolute abundance (density) of these species using lure stations with remote cameras, snow tracking transects, and visual indices.
- **Native insect diversity and distribution in riparian and mesic meadows** refers to the variety and location of native insect species, which provides insight to the status of riparian and mesic meadow systems. Invertebrate richness and biodiversity, along with species distribution, indicate habitat health. However, it may be best to initially monitor for density rather than diversity, as identification is more time consuming, more costly, and requires more specialized staff that may not be readily available.
- **Selected sensitive bird species abundance, distribution, and productivity:** Selected sensitive bird species include, but are not limited to, trumpeter swans, harlequin ducks, loons, American dippers, and kingfishers. If the park populations represent populations that are critical to species survival, they should be monitored closely for abundance, distribution (for example, using helicopter transect surveys and ground-truthing), and nest productivity (for example, using constant-effort mist netting and banding such as used by the MAPS [Monitoring Avian Productivity and Survival] program).
- **Ungulate population distribution and abundance:** Ungulate abundance refers to the number of ungulates at selected sites to be resampled, while ungulate distribution refers to locations of the ungulates across park landscapes. Abundance data are initially collected at chosen sites throughout the parks and resampled, and distribution measurements should include GPS data points of where abundance data were collected to show a landscape distribution of ungulates. This is already being performed to some degree by the Network parks and departments dealing with fish, wildlife, and parks in Montana, Idaho, and Wyoming.
- **Vertebrate diseases** affecting the GRYN include, but are not limited to, brucellosis, chronic wasting disease, West Nile virus, pasturella pneumonia, chlamydia, Rana virus, Chytrid fungus, and whirling disease. The following metrics can be used to determine actual or predicted rates of infection: carcass inspections, hunter-killed animal inspection, live animal testing, population demography sampling, and vegetation/habitat sampling (i.e. forage availability).
- **Whitebark pine decline:** Whitebark pine stands throughout the Greater Yellowstone Ecosystem are rapidly declining due to white pine blister rust, fire suppression, and mountain pine beetle infestations, thereby affecting an entire ecosystem, including grizzly bears and Clark's nutcracker populations. Possible metrics for monitoring white pine blister rust abundance and spread include repeat sampling and removal of rust-infected branches or areas of the bark. Mountain pine beetle infestations may also be monitored using repeat sampling.

D. BOARD OF DIRECTOR'S APPROVAL OF FINAL VITAL SIGNS LIST

Following the TC selection of its recommended vital signs (Table III.3), the Program Manager provided the BOD the following items for review:

- a description of the selection process,
- a list of the proposed final vital signs, as selected by the TC, and
- a short description of each vital sign describing its meaning and importance.

At a one-day meeting on August 8, 2003, the Board of Directors approved the TC recommendations as the Network's final vital signs.

The meeting began with the Program Manager reviewing the three items noted above, and then soliciting input and direction from the BOD. The Board provided helpful critiques, generally expressing satisfaction with the methodical and collaborative process that the GRYN underwent to create the list, and the variety encompassed by the list. Suggestions on how to present vital signs were made. Budgetary concerns were regularly voiced.

Regarding the "finality" of the list, the Program Manager requested that the Board recognize that:

- some minor name changes to vital signs could be expected in the future,
- as sampling protocol development begins during Phase III, some major changes may be requested for BOD approval, including addition or deletion of vital signs (such changes are anticipated by the National I&M Program) [12], and
- a strong possibility exists that the current list is outside the funding available through the Natural Resource Challenge. Chapters VIII-X of this monitoring plan will address Network staff, schedules, budgets, and leveraging necessary to implement the sampling protocol developed in Phase III.

Given these considerations, the Program Manager requested that the BOD recognize that it would be approving the Network's final vital signs list as an excellent start, with possible future modifications. All Board members present signed the approval, with absentee signatures gathered later.

E. SCIENCE COMMITTEE—PEER REVIEW AND GUIDANCE

On September 22-24, the GRYN Science Committee met to discuss and peer review the Network's:

- vital signs list (Table III.3), as selected by the Technical Committee and approved by the Board of Directors, and
- proposed framework for moving into Phase 3, including the development of monitoring and management objectives, and the creation of sampling designs and protocols for a subset of the selected vital signs.

To help the Science Committee (SC) in its major role of scientific oversight and guidance to the Network's I&M program, the Program Manager provided members a draft copy of the Phase II report before the meeting. Several members of the Technical Committee, one BOD

[12] Indeed, following a meeting of the Science Committee (held after the BOD meeting), the Program Manager used a process agreed upon by the BOD to modify the vital signs list shown in Table III.3 and thus create the Network's final Phase II vital signs list. As a result of Science Committee guidance, the Network made two additions to the list of Table III.3, and modified several vital sign names for clarity. These changes are presented in Table III.5 as part of a description of a Science Committee meeting near the end of Phase II (Section III.E).

member, and park technical staff also received advance Phase II draft copies, attended the meeting, and provided valuable input to the peer review process.

The Science Committee review of the selected vital signs and the opportunity to openly discuss and exchange critique provided many insightful and constructive comments. The following section summarizes the strengths and weaknesses of the selected vital signs, plus highlights changes adopted by the Network and guidance provided by the committee.

1. STRENGTHS AND WEAKNESSES OF THE SELECTED VITAL SIGNS

- The group of vital signs selected by the Technical Committee cover a wide range of ecosystem drivers, stressors, and response variables that appear to be comprehensive. Regarding the question of value of the vital signs as indicators of ecosystem health —either individually or as a group—the SC stated their true "value" would be difficult to judge until the monitoring objectives, spatial and temporal scale of monitoring, and metrics for each vital sign had been defined.
- The SC recognized that conceptual models are an important tool used by the Network to identify and describe ecosystem linkages and relationships among vital signs and that the conceptual models support the robustness of the suite of selected vital signs. The Committee urged the Network to continue to make use of conceptual models in Phase III by creating models that further explain linkages between vital signs and ecosystem processes. A suggestion was given that with a properly constructed conceptual model(s), the Network could "tell a story" by following any path through the model to a metric.
- The SC acknowledged that the vital signs selected represent a first, best effort, and that further development of monitoring objectives in Phase III will likely result in modifications to the vital signs list. Specific concerns that the Network is challenged to improve during Phase III include:
    - The selected vital signs are currently mismatched in scale and level of development: some are already essentially metrics; others are lumped aggregations that could conceivably be broken into dozens of metrics.
    - The value of *short-term* vital signs to a monitoring program slated at determining *long-term* ecosystem health was questioned. Whether in agreement or not, the SC recognized that the TC did include some short-term vital signs on the basis of immediate relevance to park management.
- The SC expressed concern over the Delphi survey and Vital Signs Monitoring Workshop in that these group activities may have allowed "pet projects" to be nominated as vital signs based on the interests of those who participated. The SC also acknowledged and appreciated that while the TC selection process was guided by the workshop scores, the scores alone did not determine the final selection. A comment was made that the selection of vital signs would have been improved if a goal (e.g., preferred condition) had been stated for each vital sign in advance of the selection process.

2. GUIDANCE FOR PHASE III OF THE VITAL SIGNS MONITORING PLAN

The SC suggested changes to the organization of the vital signs into categories or functional areas so that the Network might better illustrate the interconnectedness of the selected vital signs. This discussion led to the SC creating an organizational framework and two additional conceptual models for the Network's vital signs:

- Table III.5 depicts the selected vital signs[13] in a hierarchical framework organized by functional categories. Once the vital signs were categorized in this way, the absence of below ground ecosystems was noted and a suggestion to add below ground biota as a vital sign was adopted by the Technical Committee. In addition, ground water quantity and quality was split into two vital signs. These two changes resulted in a final list of 46 vital signs for Phase III.
- Figure III.4 depicts the selected vital signs in a large-scale framework using functional groups.
- The final model (Figure III.5) depicts the integration of vital signs showing linkages among categories of vital signs within physical, chemical, biological, and human groupings.

Members of the Technical Committee, BOD, and park staff present at the SC meeting largely applauded the vital signs list presentation of Table III.5. This list will serve as the Network's final vital signs list for Phase II.

[13] Note that the names of some vital signs have been edited from the TC list (Table III.5).

Table III.5: Phase II vital signs selected for the Greater Yellowstone Network. These vital signs, shown underlined and as categorized by the SC, will be carried forward into Phase III. Several vital signs have had minor name modifications since the TC selection (Table III.3). The SC recommended "below ground biota and processes" as a vital sign (lavender), plus separated groundwater into two vital signs—quantity and quality—resulting in the Network's final list of 46 vital signs. Vital signs in green are top priority for monitoring.

Physical/Chemical Environment

1. Physical climate
- a. Basic climatological measurements
- b. Glacial retreat or advance

2. Hydrology
- a. Watershed budgets
  - *i Stream flow*
  - *ii Groundwater quantity*
  - *iii. Springs and seeps distribution and hydrology*
  - *iv. Reservoir elevation*

3. Water Quality
- a. Water chemistry
- b. Groundwater quality
- c. *E.coli (Escherichia coli)*
- d. Continuous water temperature
- e. Stream sediment transport

4. Geology
- a. Geothermal
  - *i. Heat flow/ chloride flux*
  - *ii. Geothermal feature abundance and distribution*
  - *iii. Geothermal water chemistry*
- b. Earthquake activity

5. Chemical climate
- a. Atmospheric deposition of all major anions and cations
- b. Change in visibility
- c. Oversnow vehicle emissions

Human Dimensions

1. Human Use
- a. Levels, types and distribution of visitor use
  - *i. Levels of backcountry day use*
  - *ii.. Levels of backcountry overnight use*
- b. Soundscapes
- c. Land-use change

Biotic Environment

1. Terrestrial Ecosystem
- a. Vegetation Dynamics
  - *i. Landscape*
    - 1. Land-cover classification
    - 2. Fire, fuels and carbon storage
  - *ii. Community*
    - 1. Communities of concern (aspen, riparian, shrub-steppe, and alpine)
    - 2. Browse effects on riparian vegetation
  - *iii. Populations*
    - 1. Whitebark pine decline
    - 2. Forest insect and disease of concern
    - 3. Exotic plant species abundance and distribution
- b. Above-ground consumers
  - *i. Vertebrate dynamics*
    - 1. Birds
      - *a. Land bird distribution and abundance*
      - *b. Selected sensitive bird species abundance, distribution and productivity*
    - 2. Amphibian occurrence
    - 3. Mammals
      - *a. Ungulate population distribution and distribution*
      - *b. Beaver presence and distribution*
      - *c. Large carnivore population distribution and abundance*
      - *d. Meso-carnivore population*
    - 4. Vertebrate disease (native and exotic)
  - *ii. Invertebrates*
    - 1. Native insect diversity and distribution in riparian and mesic meadows
- c. Ground surface and subsurface ecosystems
  - *i. Soil structure and stability*
  - *ii. Belowground biota and processes*

2. Aquatic Ecosystem
- a. Primary producers
  - *i. Algal species composition and biomass*
- b. Consumers
  - *i. Native aquatic community structure and composition*
  - *ii. River invertebrate assemblages*
  - *iii. Exotic aquatic community structure and composition*

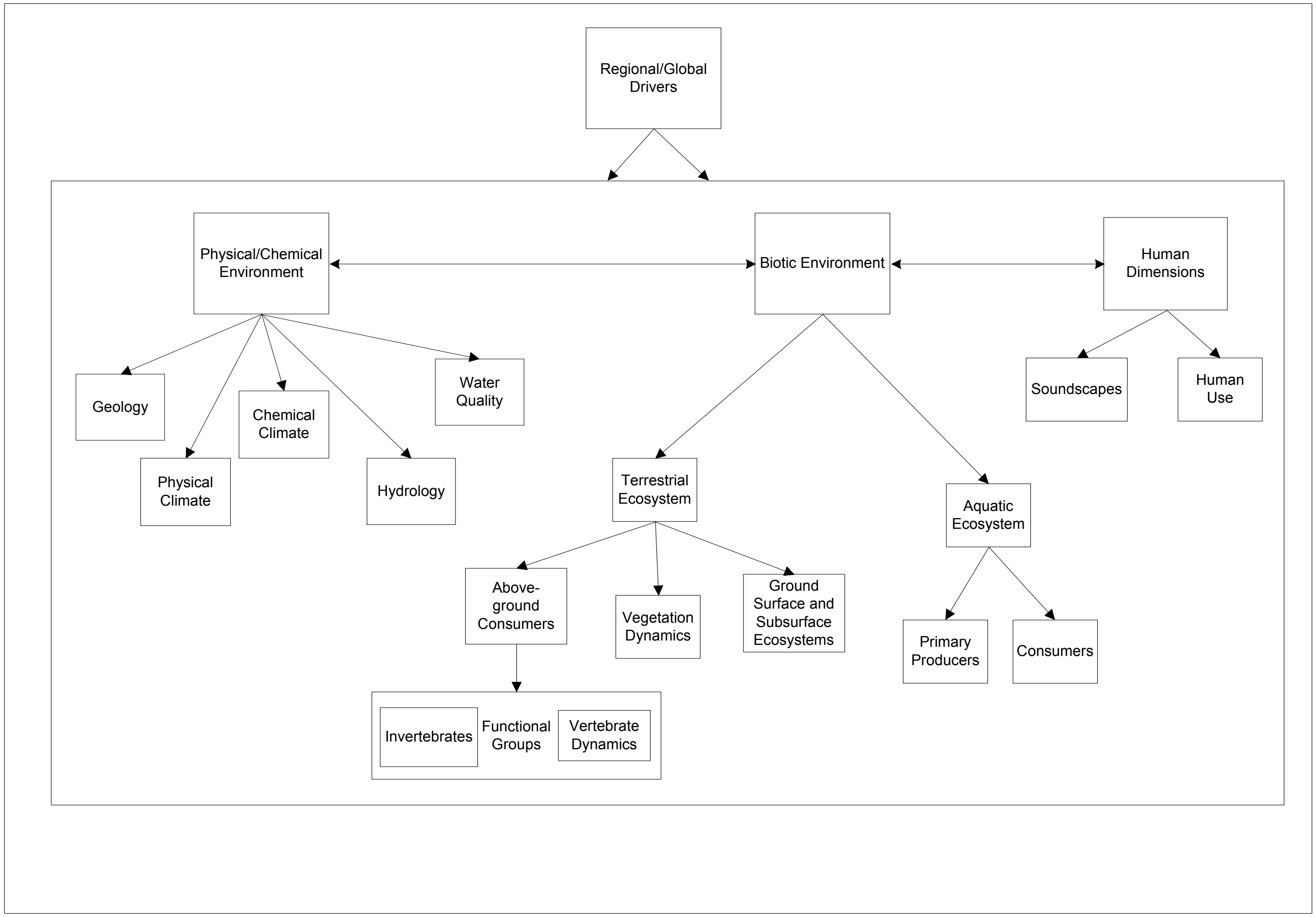

Figure III.4: Integration of vital signs showing among physical and chemical, biological, and human groupings (see Table III. 5 for category hierarchy).

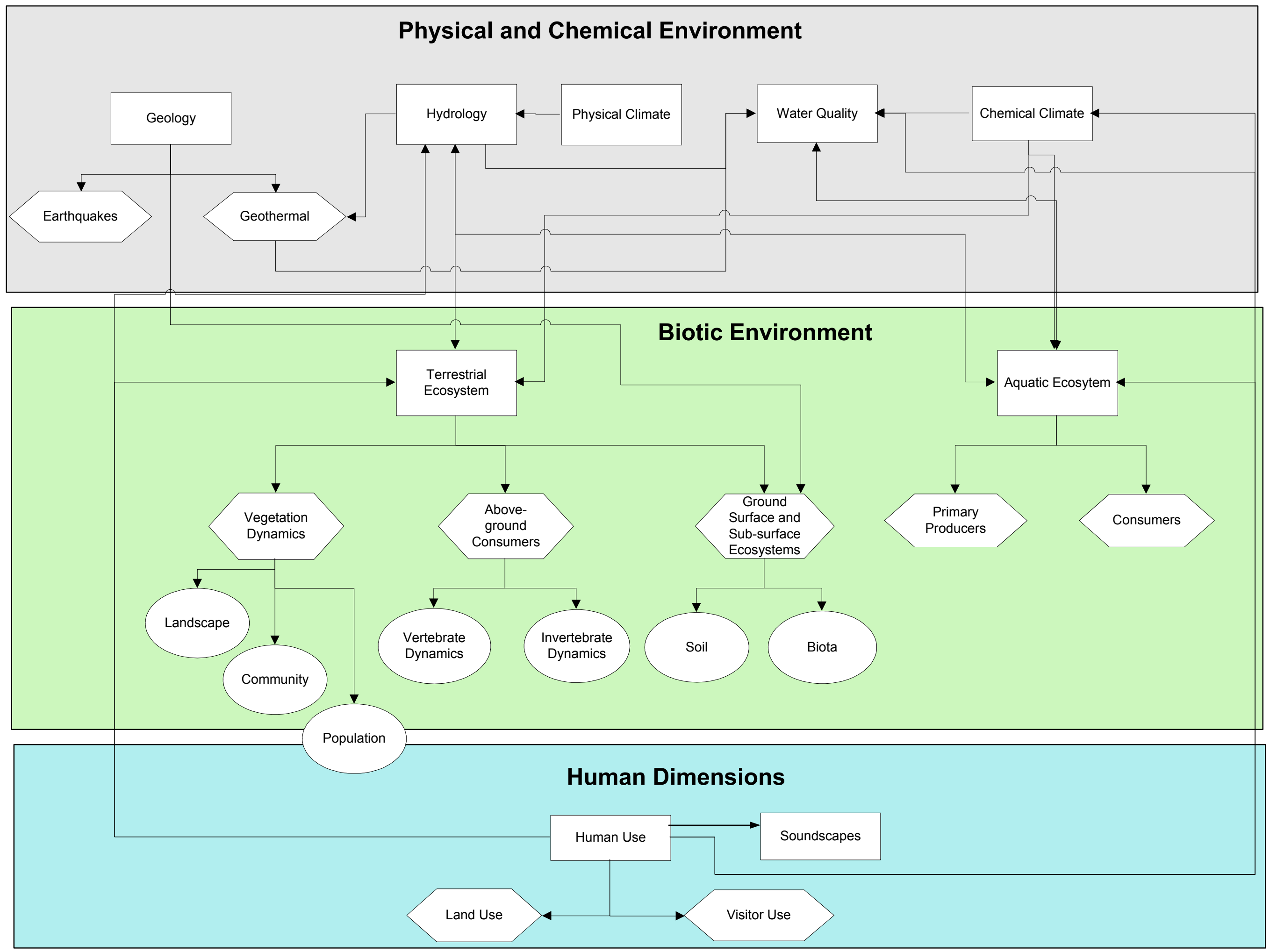

Figure III.5: Interrelationships among vital sign categories. Integration of vital signs showing linkages among categories of vital signs within physical and chemical, biological, and human groupings (see Table III.5 for category hierarchy).

F. PHASE III—NEXT STEPS

With the selection of the GRYN's vital signs list complete, the Network will focus on developing monitoring objectives, followed by sampling design and sampling protocols. It is important to recognize that monitoring programs for only a subset of the 46 vital signs are expected by the end of Phase III.

As part of its strategy for moving into the monitoring component of Phase III, the Network adopted the process described by Caughlan and Oakley (2001), with several modifications to meet specific Network needs (Figure III.6). Most of the modifications consist of slight changes in terminology, plus the addition of a few steps in the graphical representation that were implicit within the Caughlan and Oakley process.

The most substantive change in the GRYN framework is the elimination of Caughlan and Oakley's use of budgetary constraints early in the process. The Network agrees with Hinds (1984) and Caughlan and Oakley that costs should be a consideration throughout the process and that a successful program must be cost effective, in addition to ecologically relevant and statistically sound. However, the GRYN has chosen not to use cost as an initial constraint in determining what should be monitored (even Caughlan and Oakley suggest "the process of setting objectives probably should occur without the consideration of budgetary costs"). Thus, the Network's aim for excluding budgetary constraints from the graphical representation is merely to avoid any misperception that costs were used to preclude elements deemed ecologically important during initial planning.

However, costs need to be considered throughout all phases and funding may limit such things as the intensity and periodicity of monitoring, and may, in some cases, result in the need to drop some vital signs from monitoring. It is the Network's intent to develop a comprehensive monitoring plan, which includes explicit identification of the tradeoffs imposed by costs and budgetary constraints. Such an approach should improve the GRYN's ability to leverage data and funding from existing programs, help solicit outside funding to augment existing funds, and prioritize efforts to maximize the benefits derived from monitoring in those cases where tradeoffs are inevitable.

The process described by Caughlan and Oakley (2001) consists of three major stages—design, testing, and implementation—as shown in Figure III.6. There are two major steps in the process. Those identified in boxes represent steps that result in a tangible product or piece of information. Steps identified in diamonds represent decisions that do not result in a specific product unto themselves. Each of the steps, as adopted and adapted by the GRYN, is described below.

1. THE DESIGN PHASE

- ***Develop broad goals and identify vital signs***–The broad goals for the vital signs monitoring program have already been developed and are presented in Table I.6. In addition, the vital signs have also been identified and are presented in Table III.5.
- ***Review existing data***–The existing data should be analyzed to determine if any estimates of background variation exist (e.g., sampling, spatial, and temporal). These data also may offer insights on formulating hypotheses about the vital sign of interest.

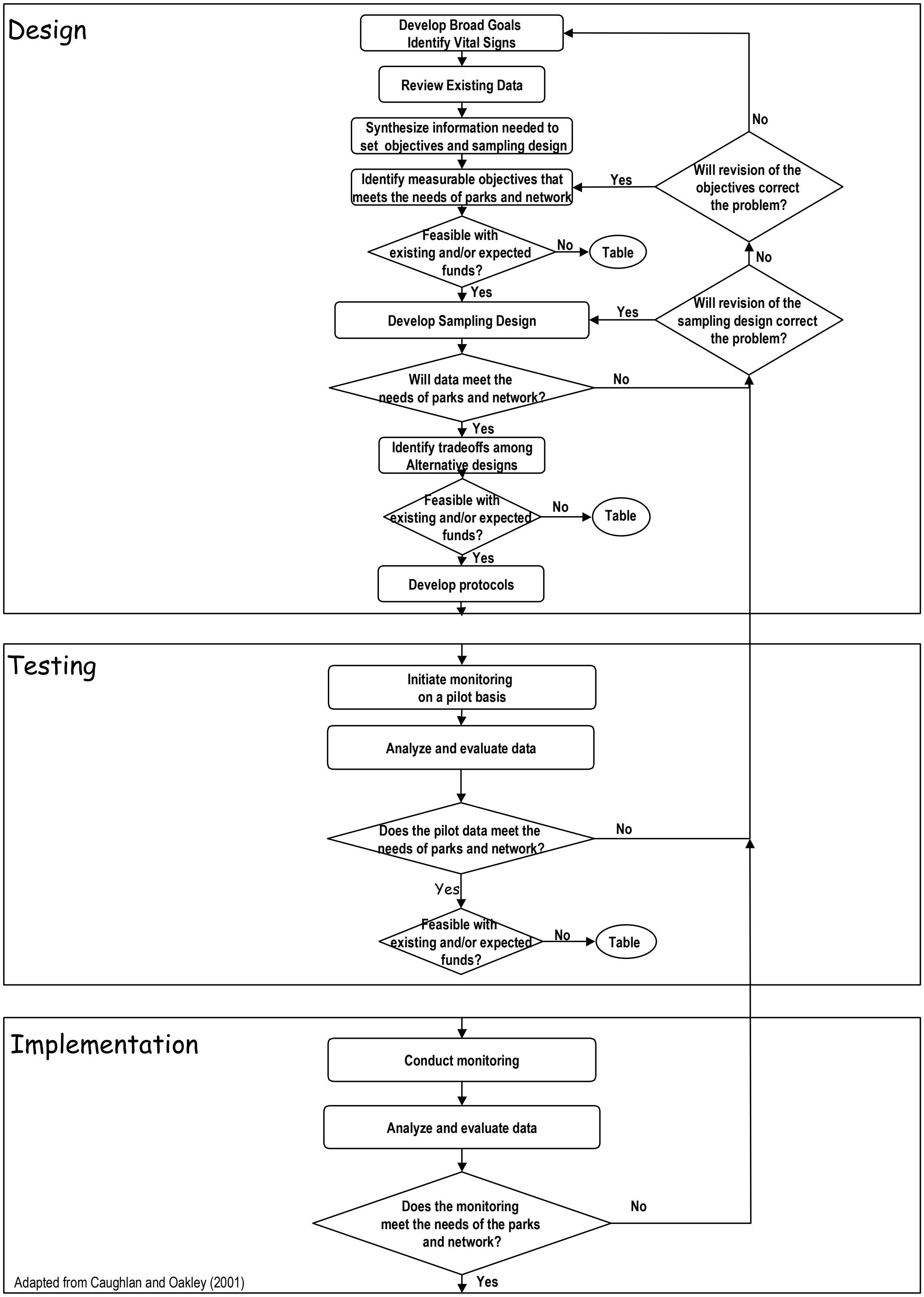

Figure III.6: Framework for GRYN Phase III monitoring program development.

- ***Synthesis of information needed to set monitoring objectives and to develop a sampling design***–Although this step is implicit in the process described by Caughlan and Oakley (2001), we believe that it is important enough to warrant explicit identification, as follows:

Synthesis of information will focus on:	Some information needed to develop the sampling design would include, but is not limited to:
▪ Conceptual models of how the vital sign is a component and interacts with other components of the GRYN ▪ Major issues and threats associated with the vital sign ▪ The expected use of resulting data (e.g., as baseline data, to support decisions, or science) ▪ Any decisions that potentially result from the data ▪ Any relevant linkages to other vital signs ▪ Any regulations or mandates that will influence what or how data are to be collected	▪ Any regulations or mandates that will influence what or how data are to be collected ▪ Information about potential sites and the population of interest ▪ Desired precision (type I error rates) ▪ Acceptable type II error rates ▪ Sampling variation (from review of existing data) ▪ Spatial and temporal variation (from review of existing data) ▪ Spatial and temporal scopes of interest (e.g., short vs. long term needs, and local vs. regional needs).

- ***Identify measurable objectives that meet the needs of the parks and Network–*** *Identification* of specific meaningful and measurable monitoring objectives is recognized as one of the most difficult and important steps of developing a monitoring program (e.g., Silsbee and Petersen 1993, Schmoldt et al. 1994, Pastorok et al. 1997, Vos et al. 2000, Caughlan and Oakley 2001).

  Monitoring objectives should explicitly express the state (value) or dynamics to be measured and, whenever possible, should include desired levels of precision and available information (i.e., expected variation, desired type I error rate, and magnitude of change that we are trying to detect) to estimate statistical power and type II error rates (Elzinga et al. 1998).

  In contrast to *management* objectives, which set a specific goal for attaining some ecological condition or change value, *monitoring* objectives set a specific goal for the measurement of that value (Elzinga et al. 1998). However, to ensure relevance of resulting data, monitoring objectives will be developed that reflect management objectives whenever the latter are explicitly known and when the vital sign is intended to reflect the degree to which management activities are successful.

- ***Feasible with existing and/or expected funds?***–At this point, costs are ill defined, and represent only a crude indication of feasibility. It should be noted that this checkpoint does not attempt to determine if the objectives are suitable to meet the needs of the parks and/or the Network. Consequently, this checkpoint would not result in a re-examination of the objectives or vital sign unless there was an explicit reason to think that a more cost-effective alternative was overlooked.

- ***Develop sampling design***–Based on the synthesis of information, the review of existing data, and clearly defined monitoring objectives, sampling designs will be developed that meet the requirements described by Hinds (1984) of being ecologically relevant, statistically sound, and cost effective. Because of the normal uncertainties of funding, we will adopt a tiered approach that can accommodate different levels of funding (Caughlan and Oakley 2001), using designs that differ in levels of precision and/or inclusion or exclusion of particular elements. Thus, we would enable prioritizing implementation of monitoring options based on informed choices of explicitly identified tradeoffs (see below).

- ***Will data meet monitoring needs of the parks and/or Network?***– If it appears that design will satisfy the monitoring objectives then we move forward in the process. If not, then the Network will need to (1) revise the methods, (2) re-examine the monitoring objectives if a suitable design is not attainable, or (3) re-examine the vital sign, if unable to find a solution by changing the methods or objectives.
- ***Identify tradeoffs among alternative designs***– Caughlan and Oakley (2001) state that there are costs associated with developing alternative designs, but the Network believes that most of those costs are incurred during gathering the information and defining the specific objectives, and that the benefits of having alternatives at this point are worth the possible additional costs.
- ***Feasible with existing and/or expected funds?***– At this point the costs have been estimated, but not verified from field efforts. It should be noted that this checkpoint does not imply anything about whether the objectives are suitable to meet the needs of the parks and/or the Network. Consequently this checkpoint would not result in a re-examination of the objectives or vital sign unless there was an explicit reason to think that a more cost-effective alternative was overlooked.
- ***Develop protocols***–If the design for a given vital sign has passed all checks to this point, then development of protocols in accordance with the guidelines of the National I&M Program would begin.

2. THE TESTING PHASE

- ***Initiate monitoring on a pilot basis***–This step constitutes a field-testing of monitoring for one or more objectives of one or more vital signs. At this stage it is assumed that the objectives and sampling designs will meet the needs and goals of the parks and/or the Network.
- ***Analyze and evaluate the data***.–This is the first point for which real data can be used to determine if the monitoring objectives, sampling design, and protocols are adequate to meet the needs and goals of the parks and/or the Network.
- ***Will data meet monitoring needs of the parks and/or the Network?***– If it appears that the current objectives, design, and protocols will satisfy the monitoring objectives, then the implementation phase will begin (after a re-check of cost feasibility). If not, then the Network will (1) revise the methods, (2) re-examine the monitoring objectives if a suitable design is not attainable, or (3) re-examine the vital sign, if unable to find a solution by changing the methods or objectives.
- ***Feasible with existing and/or expected funds?***– At this point the costs have been estimated and can be verified from field efforts. It should be noted that this

checkpoint does not imply anything about whether the objectives are suitable to meet the needs of the parks and/or the Network. Consequently this checkpoint would not result in a re-examination of the objectives or vital sign unless there was an explicit reason to think that a more cost-effective alternative was overlooked.

3. The Implementation Phase

- ***Conduct monitoring***–This phase consists of the implementation of field monitoring for one or more objectives of one or more vital signs. At this stage it is believed, and pilot efforts have supported, that the objectives and sampling designs will meet the needs and goals of the parks and/or the Network.
- ***Analyze and evaluate the data***–This is the first point for which real data can be used to determine if the monitoring objectives, sampling design, and protocols are adequate to meet the needs and goals of the parks and/or the Network. At this stage the Network will attempt to ensure that the analyses and reporting of data are in a form that meets the needs of the parks, and are presented in time frames that fit within the annual reporting and decision needs of the parks.
- ***Will data meet monitoring needs of the parks and/or the Network?***– If it appears that the current objectives, design, and protocols will satisfy the monitoring objectives, then the Network will begin the implementation phase (after a re-check of cost feasibility). If not, then the Network will (1) revise the methods, (2) re-examine the monitoring objectives if a suitable design is not attainable, or (3) re-examine our vital sign, if unable to find a solution by changing the methods or objectives.

G. CLOSING PHASE II—A CONTINUING REQUEST FOR PEER REVIEW

As it did in Phase II, the Greater Yellowstone Network will continue to solicit peer review throughout Phase III. Review of the Network's program, including review of this document, is always welcomed and encouraged. Anyone reading this Phase II report—regardless if the reader is part of the group explicitly identified as peer reviewers for the document—is invited to contact the Program Manager with thoughts on how the GRYN can improve its program.

IV. SAMPLING DESIGN

To be completed in Phase III.

V. SAMPLING PROTOCOLS

To be completed in Phase III.

VI. DATA MANAGEMENT

To be completed in Phase III.

VII. DATA ANALYSIS AND REPORTING

To be completed in Phase III.

VIII. ADMINISTRATION/IMPLEMENTATION OF THE MONITORING PROGRAM

To be completed in Phase III.

IX. SCHEDULE

To be completed in Phase III.

X. BUDGET

To be completed in Phase III.

XI. LITERATURE CITED

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XII. ACRONYMS

Acronym	Definition
ANC	Acid-Neutralizing Capacity
APHIS (USDA)	Animal and Plant Health Inspection Service
ARD (NPS)	Air Resources Division
BICA	Bighorn Canyon National Recreation Area
BLM	Bureau of Land Management
BOD	Board of Directors
BRD (USGS)	Biological Resources Disiplines
CASTNet	Clean Air Status and Trends Network
CEM	Cumulative Effects Model
CFC	Chlorofluorocarbons
EPA	Environmental Protection Agency
ESA	Endangered Species Act
GPRA	Government Performance and Results Act
GPS	Global Positioning System
GRTE	Grand Teton National Park
GRYN	Greater Yellowstone Inventory and Monitoring Network
GYE	Greater Yellowstone Ecosystem
HUC	Hydrologic Unit Code
I&M	Inventory and Monitoring
IGBST	Interagency Grizzly Bear Study Team
IMPROVE	Interagency Monitoring of Protected Visual Environments
JODR	John D. Rockefeller, Jr. Memorial Parkway
MAPS	Monitoring Avian Productivity and Survival
MSU	Montana State University

MTDEQ	Montana Department of Environmental Quality
NADP/NTN	National Atmospheric Deposition Program/National Trends
NAWQA (USGS)	National Water-Quality Assessment Program
NOAA	National Oceanic and Atmospheric Administration
NPS	National Park Service
NRA	National Recreation Area
NRC	National Research Council
NRCS	Natural Resources Conservation Service
NSIDC	National Snow and Ice Data Center
NVCS	National Vegetation Class Standards
ONRW	Outstanding Natural Resource Water
PAO	Proportion of Area Occupied
SC	Science Committee
T&E	Threatened and Endangered Species
TC	Technical Committee
TMDL	Total Maximum Daily Loads
USDA	United States Department of Agriculture
USDI	United States Department of the Interior
USFS	United States Forest Service
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
UW	University of Wyoming
UV	ultraviolet radiation
WCS	Wildlife Conservation Society
WGF	Wyoming Game and Fish
WYDEQ	Wyoming Department of Environmental Quality
YELL	Yellowstone National Park
YVO	Yellowstone Volcano Observatory

XIII. GLOSSARY

- **Candidate vital sign**: The prioritized indicators from the Vital Signs Monitoring Workshop that were used by the Technical Committee to create the vital signs list for approval by the Board of Directors.
- **Driver**: The major external driving forces that have large-scale influences on natural systems. Drivers can be natural forces or anthropogenic.
- **Endangered**: Any species that is in danger of becoming extinct throughout all or

a significant portion of its range.

- **Inventory**: An extensive point-in-time survey to determine the presence/absence, location or condition of a biotic or abiotic resource.
- **Metrics (Measurements)**: Specific measures used to quantify the indictors. Analysis of this information will assess how well the indicator is responding to the ecological effect.
- **Monitoring**: The collection and analysis of repeated observations or measurements to evaluate changes in condition and progress toward meeting a management objective.
- **Outcome:** Ecological attributes that result from effects within which specific processes or factors may become vital signs.
- **Proposed candidate vital sign**: Indicators chosen during the Delphi and conceptual modeling processes, and then given to the Vital Signs Monitoring Workshop participants for prioritization.
- **Proposed final vital signs**: Vital signs selected by the Technical Committee, though not yet approved as "final" by the Board of Directors.
- **Response Variables**: Physical, chemical, and biological responses to drivers and stressors.
- **Stressor**: Physical, chemical, or biological agents that cause significant changes in the ecological components, patterns, and relationships in natural systems. The effects of stressors on park resources can be positive or negative. ***The difference between a Driver and a Stressor is in some cases a matter of scale. For example, exotic species invasions, land-use change, and fire suppression can be a driver in cases where they have a national or regional effect, but at a more localized scale they may be stressors.*
- **Threatened**: A species that is likely to become endangered in the foreseeable future.
- **Vital Signs**: Vital signs are a subset of physical, chemical, and biological elements and processes of park ecosystems that are selected to represent the overall health or condition of park resources, known or hypothesized effects of stressors, or elements that have important human values. The elements and processes that are monitored are a subset of the total suite of natural resources that park managers are directed to preserve "unimpaired for future generations," including water, air, geological resources, plants and animals, and the various ecological, biological, and physical processes that act on those resources. Vital signs may occur at any level of organization including landscape, community, population, or genetic level, and may be compositional (referring to the variety of elements in the system), structural (referring to the organization or pattern of the system), or functional (referring to ecological processes).